

# Residues from waste incineration

Final report PSO-5784

**Astrup, Thomas; Pedersen, A.J.; Hyks, Jiri; Frandsen, F.J.**

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# Residues from waste incineration

## Final report PSO-5784

Revised version

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Thomas Astrup
Anne Juul Pedersen
Jiri Hyks
Flemming J. Frandsen

DTU Environment
Department of Environmental Engineering

# Preface

This project was carried out by DTU Environment and DTU Chemical Engineering in close collaboration with the industrial partners: Amagerforbrænding, Vestforbrænding, AffaldVarme Århus, DONG Energy, FASAN, Babcock & Wilcox Vølund, ALSTOM, and AFATEK. The project was financed partly by the research grant PSO-5784 and partly by the involved industrial partners. The project period was 2005-2009.

The primary objective of the project was to improve the understanding of ash formation (fly ashes and bottom ashes) in waste incinerators and in this context to evaluate the importance of the waste input and the mode of operation.

The collaboration between the involved partners has been very fruitful. The joined forces of DTU Environment and DTU Chemical Engineering in cooperation with the numerous industrial partners has ensured a strong interdisciplinary project, covering all aspects of waste incineration, from the characteristics of the incoming waste, through the combustion characteristics and the ash formation processes in the furnace/boiler system, deposit formation and corrosion aspects, to the final emissions and the quality of the produced combustion residues. It is our conviction that this collaboration has been very profitable for the progresses of the project, and, in particular, for the robustness of our conclusions.

This Final Report is based on scientific contributions by: Thomas Astrup, Jiri Hyks and Christian Riber from DTU Environment; Anne Juul Pedersen, Flemming J. Frandsen, Jacob H. Zeuthen and Jørn Hansen from DTU Chemical Engineering; and Søren Nymann Thomsen from Babcock & Wilcox Vølund. The contributions are greatly acknowledged.

Based on the project results the following scientific journal papers have been prepared:

(I) Astrup, T., Riber, C. & Pedersen, A.J. (2009): MSW Incinerator Emissions and Residues: Influence of Waste Input and Operational Conditions. *Manuscript.*

(II) Pedersen, A.J., Frandsen, F.J., Riber, C., Astrup, T., Thomsen, N.S., Lundtorp, K. & Mortensen, L.F. (2009): A Full-Scale Study on the Partitioning of Trace Elements in Municipal Solid Waste Incineration – Effects of Firing Different Waste Types. *Energy Fuels*, 2009, **23 (7)**, 3475–3489.

(III) Zeuthen, J.H., Pedersen, A.J., Hansen, J., Frandsen, F., Livbjerg, H., Riber, C. & Astrup, T. (2007): Combustion aerosols from municipal waste incineration - effect of fuel feedstock and plant operation. *Combustion Science and Technology*. **179**, 2171-2198.

(IV) Hyks, J. & Astrup, T. (2009): Influence of operational conditions, waste input and ageing on leaching of contaminants from waste incineration bottom ashes. *Chemosphere*, **76**, 1178-1184.

(V) Frandsen, F. J.; Pedersen A. J.; Hansen, J.; Madsen, O. H.; Lundtorp, K.; Mortensen, L. (2008): Deposit Formation in the FASAN WtE Boiler as a Function of Feedstock Composition and Boiler Operation. *Energy Fuels*, 2009, **23 (7)**, 3490–3496.

In the text these papers are referred to by their roman numerals. The papers are not included in this public report; however, they are available from the Technical University of Denmark, see note on page vii.

The authors wish to express our sincere gratitude towards all partners in the project as well as others involved for the interest in the project and the willingness to contribute with suggestions and comments. A special thank is forwarded to participants in the two project workshops for their detailed interest in our work, and to the people of FASAN for participating in the measuring campaign.

Last but not least, the authors wish to acknowledge the other members of the project group for their always committed involvement in the project: Uffe Juul Andersen (Amagerforbrænding), Hanne Rasmussen (AffaldVarme Aarhus), Kim Crillesen (Vestforbrænding), Kirsten Reinholdt Bojsen (Vestforbrænding), Kasper Lundtorp (Babcock & Wilcox Vølund), Bo Sander (DONG Energy), Jesper Staal (DONG Energy), Niels Ole Knudsen (Vattenfall), Jens Strandgaard (FASAN), Leif F. Mortensen (FASAN), Lars-Erik Johansson (ALSTOM), Stefan Ahman (ALSTOM), Dan H. Pedersen (ALSTOM), Jens Kallesøe (AFATEK), Ann Birgitte Sørensen (AFATEK). A special thanks to our former DTU colleague Christian Riber (now Rambøll) for his significant contributions to the project.

# Summary

The primary objective of the project was to improve the understanding of the formation and characteristics of residues from waste incineration. The project had specific focus on the importance of the waste input and the mode of operation.

The main project work was carried out by DTU Environment and DTU Chemical Engineering in close collaboration with a number of industrial partners. The aim was to cover all aspects of waste incineration: from the characteristics of the incoming waste, through the combustion processes and ash formation in the furnace/boiler system, deposit formation and corrosion aspects, to the final air emissions and the leaching properties of the generated residues.

The project was focused around a full-scale measurement campaign at the FASAN incinerator in Næstved. Samples of bottom ashes and fly ash particles were collected and measurements of gases, aerosols and deposit build-up were carried out. During the campaign, a series of experiments were completed with i) changes in the waste input composition, and ii) changes in furnace operational parameters. Characterization of ash samples were subsequently carried out in the lab. Additional ash samples were collected from a range of Danish waste incinerators during the course of a year to establish a comparable set of ash data for Danish conditions. These samples were characterized with respect to solid composition and leaching properties as well.

In total 12 experiments were carried out at the FASAN incinerator: six with changes in waste input and six with changes in operational conditions, including one reference experiment. In experiments with changes in the waste input six waste material fractions were added one-by-one to a base-load waste defined as the normal waste received at the incinerator, excluding certain industrial waste types to minimize the possibilities for unnecessary variations in the input waste composition. The following waste materials were used (fraction per wet weight in parentheses):

- Road De-icing Salt (0.5 %)
- Shoes (1.6 %)
- Automobile Shredder Waste (14 %)
- Batteries (0.5 %)
- PVC (5.5 %)
- Chromate-Cupper-Arsenate Impregnated Wood (11 %)

During experiments involving changes waste input composition the incinerator was operated as close as possible to standard conditions. During experiments with changes in operational conditions, the incinerator was fed with the base-load waste only. Five experiments were carried out with operational conditions outside normal operation. The parameters changed were:

- Two experiments with changes in oxygen level: Minimum and Maximum $O_2$
- Two experiments with changes in air supply distribution: Decreased and Increased secondary air
- One reference experiment with standard furnace conditions

- One experiment in which the furnace showed unstable/undefined conditions and incomplete combustion on the grate as an example of a worst case scenario

Overall, it was found that the waste input composition significantly affected the characteristics of the generated residues. A similar correlation between operational conditions and residue characteristics could not be observed. Consequently, the project recommended that optimization of residue quality should focus on controlling the waste input composition. The project results showed that including specific waste materials (and thereby also excluding the same materials) may have significant effects on the residue composition, residue leaching, aerosol and deposit formation, as well as stack emissions. It is specifically recommended to minimize Cl in the input waste. Clean gas concentrations of As, Cd, Cr, Hg, and Sb appeared to be significantly affected by the input waste composition: Impregnated Wood (As, Cr), Batteries (Cd, Hg), and PVC (Sb). Based on the project results, it was found that a significant potential for optimization of emissions from waste incineration exists. Focus is recommended to be on the waste input composition.

Based on mass balance calculations, the following elements appeared enriched in the waste used in the individual experiments with changes in waste composition:

- Road De-icing Salt: Na, Cl
- Shoes: Cd, Cl
- Automobile Shredder Waste: Ba, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Sn, V, Zn
- Batteries: Cd, Co, Hg, S, Sr
- PVC: Cd, Cl
- Chromate-Cupper-Arsenate Impregnated Wood: As, K, Pb, S, Si

In some cases, these enrichments were associated with higher concentrations in the solid residues (e.g. As, Cu, and Mo) while in other cases this was not reflected in the residues (e.g Cr, Ni, and Pb) indicating that other mechanisms were important also. Cl in the waste appeared to have a special role as this element affected several aspects:

- Organic bound Cl appeared released preferably to the gas phase while inorganic bound Cl was found primarily in the bottom ashes
- Cl increased formation of volatile (and more corrosive) Pb species while S had the opposite effect of forming more stable (and less corrosive) Pb species
- Cl appeared to increase the mass-load of aerosols if present as alkali-chloride
- Cl appeared to increase deposition fluxes

In general, no clear correlation between waste composition/operational conditions and the leaching properties could be observed. Only in the case of Cl leaching a significant relation to the solid content of the bottom ashes was found (only in experiments with changes in the waste input). Overall, less than 20 % of the solid Cl in the bottom ash samples appeared leachable. The observed variations in leaching data generally appeared within the ranges observed for typical bottom ashes collected from a range of different Danish plants (generally about one order of magnitude between high and low values for leachate concentrations).

The data provided by the project can form a solid basis for carrying out life-cycle assessments of waste incineration and provide input to authorities for evaluating the consequences of incineration of specific waste materials.

# Contents

# Appendices

(I) Astrup, T., Riber, C. & Pedersen, A.J. (2009): MSW Incinerator Emissions and Residues: Influence of Waste Input and Operational Conditions

(II) Pedersen, A.J., Frandsen, F.J., Riber, C., Astrup, T., Thomsen, N.S., Lundtorp, K. & Mortensen, L.F. (2009): A Full-Scale Study on the Partitioning of Trace Elements in Municipal Solid Waste Incineration – Effects of Firing Different Waste Types

(III) Zeuthen, J.H., Pedersen, A.J., Hansen, J., Frandsen, F., Livbjerg, H., Riber, C. & Astrup, T. (2007): Combustion aerosols from municipal waste incineration - effect of fuel feedstock and plant operation

(IV) Hyks, J. & Astrup, T. (2009): Influence of operational conditions, waste input and ageing on leaching of contaminants from waste incineration bottom ashes

(V) Frandsen, F.J.; Pedersen A.J.; Hansen, J.; Madsen, O.H.; Lundtorp, K.; Mortensen, L. (2008): Deposit Formation in the FASAN WtE Boiler as a Function of Feedstock Composition and Boiler Operation

(VI) Operational conditions and flue gas data for the FASAN experiments

(VII) Reside characteristics: solid composition and leaching

(VIII) Modeling of heterogeneous condensation

Appendices (I) through (V) are not included in this public version of the report but printed versions of the papers may be freely obtained from the Technical University of Denmark: appendices (I) and (IV) from the library at Department of Environmental Engineering (library@env.dtu.dk), appendices (II), (III), and (V) from Department of Chemical Engineering (chec@kt.dtu.dk).

# 1. Introduction

## Background

Municipal solid waste is receiving increased attention as a fuel for supplementing existing energy production in many countries and waste incineration is in some countries an important treatment option for the solid waste generated by households and industry. Modern waste incinerators offer a proven way to route waste away from landfills and at the same time facilitate recovery of the energy contained in the waste. The most important environmental concerns related to municipal solid waste incinerators are typically associated with emission of specific components to air (e.g. metals, acids, chlorides, and organic compounds), however a major part of the pollution potential is left in the residues, and contaminants released from these solid outputs after final disposal can be significant in a longer time perspective (Astrup et al. **I**). Today, operation of modern waste incinerators involves complying with strict regulatory limit values for air emissions while at the same time optimizing energy recovery and generating bottom ashes with characteristics useful for utilization as secondary construction materials. Optimal performance of an incinerator within this framework requires an in-depth understanding of the influences from the waste input as well as the furnace operation and combustion conditions.

Stable furnace operation greatly relies on good mixing of the incoming waste in the bunker and continuous feeding of the waste hopper, however waste composition may change over time and individual furnace operators may take different approaches to mixing and feeding. While waste received from households may vary relatively little over the week, waste received from commercial and industrial sectors may vary significantly during the course of a week: a specific plastic processing industry may for example deliver a truckload of waste plastic every Friday thereby significantly affecting the composition of the waste input during weekend. Individual operators may respond differently to such challenges applying different mixing of the waste in the bunker and consequently induce varying furnace conditions. These time-wise variations may then be addressed differently by furnace operators potentially leading to variations in air emissions and residue quality. In order to further optimize furnace operation and to increase robustness of furnace designs, an improved understanding of the responses to variations in waste input composition as well as furnace operational parameters are important.

Existing investigations of municipal solid waste incinerators have so far focused primarily on individual aspects of incinerator performance, e.g. residue characteristics, air emissions, or mass flows in the incinerator, but limited focus has been placed on the potential combined effects caused by variations in waste input or the significance of changes in operational parameters. Within recent years, significant efforts has been carried out in Denmark focusing on characterizing leaching from residues from waste incineration; however the focus has by far in most cases been placed on the residues themselves without linking back to the incinerator.

In order to fully assess environmental consequences from waste incineration (air emissions and residues), the influence from such variations should be quantified. If not we may fail to realize whether emission reductions are within reach or whether choices in waste sorting and management may have negative effects when treating

waste thermally. The overall aim of this project is to improve the understanding of the link between the residues and the conditions within the incinerator.

## Objectives

The primary objective of the project was to improve the understanding of ash formation (fly ashes and bottom ashes) in waste incinerators and in this context to evaluate the importance of the waste input and the mode of operation. Specifically this involved to:

- Investigate the importance of specific waste fractions for generation of solid residues
- Investigate the importance of operation conditions for generation of solid residues
- Improve the understanding of gas-particle partitioning in waste incinerators
- Evaluate the potential for optimization of plant operation with respect to improvement of residue quality
- Evaluate the consequences of sorting out or including specific waste fractions in the waste input with respect to solid residue generation
- Evaluate the potential for selective/alternative capture of fly ashes
- Evaluate the overall potential for optimization without affecting negatively the overall plant performance
- Establish a coherent and systematic dataset describing waste composition and residue characteristics from a range of Danish waste incinerators as well as variations in these data between plants and over time for a selected plant

## Project outline

### Overview

The project was focused around a full-scale measurement campaign at the FASAN incinerator in Næstved. Samples of bottom ashes and fly ash particles were collected and measurements of gases and aerosols were carried out. During the campaign, a series of experiments were completed with i) changes in the waste input composition, and ii) changes in furnace operational parameters. Characterization of ash samples were subsequently carried out in the lab. Additional ash samples were collected from a range of waste incinerators during the course of a year. These were characterized in the lab as well.

### Experimental approach

A "base-load waste" was defined per weight as approximately 80 % municipal solid waste from households and approximately 20 % "combustible waste" from recycling stations. This waste was identical to the waste normally received at the incinerator but without the industrial waste fractions which could potentially cause unnecessary fluctuations in the input composition during the experiments. The base-load waste had an average lower heating value (LHV) around 9 GJ/ton.

During experiments involving changes in operational conditions, the incinerator was fed with base-load waste only. During experiments involving changes in waste input composition, known amounts of specific material fractions were added to the base-load waste while ensuring that the LHV of the combined waste was within the incinerators design range.

**The FASAN incinerator**

The experiments were carried out at the FASAN incinerator in Næstved. The incinerator furnace (waste capacity of 8 ton/hour at a LHV of 12 GJ/tonne, corresponding to a thermal boiler capacity of about 96 GJ/hour) was designed by Babcock & Wilcox Vølund and equipped with an air-cooled grate system. The furnace was commissioned in 2005. Flue gas cleaning was carried out by an ALSTOM NID (Novel Integrated Desulphurization) system with injection of hydrated lime and a subsequent bag filter system.

**Measurements and sampling**

Data and parameters collected during the measurement campaign at FASAN are outlined in Table 1. Gaseous emissions: $CO_2$, CO, $O_2$, $NO_x$, Cl, $SO_2$, metals, dust and aerosols. Solid residues: major and minor inorganic elements and inorganic/organic carbon. Furnace operation: mass loaded to the incinerator, produced energy, generation of solid outputs. Log data from the furnace operational system were collected as 10 minutes average values (see Astrup et al. **I** for details).

Stack gases after flue gas cleaning (see Figure 1) were sampled using standard techniques for determination of stationary source emissions (gas extraction, filtering and wash bottles for metal capture). Major gas components ($O_2$, $CO_2$, CO, NO and $SO_2$) were continuously measured at the top of the furnace at the entrance to the superheater section (temperatures around 490°C-590°C) using gas extraction probes and standard gas analyzers. Fly ash particles were sampled isokinetic using a steel probe placed in three positions across the main flue gas duct after the boiler section (see Figure 1), please refer to Pedersen et al. (**II**) for details. Aerosols were measured by Low Pressure Cascade Impactor (LPI) and Scanning Mobility Particle Sizer (SMPS) to allow for characterization of aerosol mass, particle size distribution, and chemical composition. Please refer to Zeuthen et al. (**III**) for details on aerosols.

*Table 1. Parameters monitored during the full scale experiments at FASAN.*

| | | |
|---|---|---|
| **Furnace** | State | Flow rate input, grate velocity, air distribution, temperatures |
| **Gas** | State | Temperature, pressure, flow rate |
| | Major components | $CO_2$, $H_2O$, $O_2$, $SO_2$, $NO_x$, HCl |
| | Minor components | Dioxin, metals, salts, CO, HF, dust, aerosols |
| **Residues** | State | Temperature, flow rate, pH, conductivity |
| | Major components | $H_2O$, Cl, Fe, Al, Cu, TOC |
| | Minor components | Other metals, salts, $SO_4$ |
| **Auxiliary materials** | State | Energy content, flow rates |
| | Major components | $H_2O$, Metals, salts |
| **Energy** | State | Production rate |
| **Ambient** | State | Temperature, humidity |

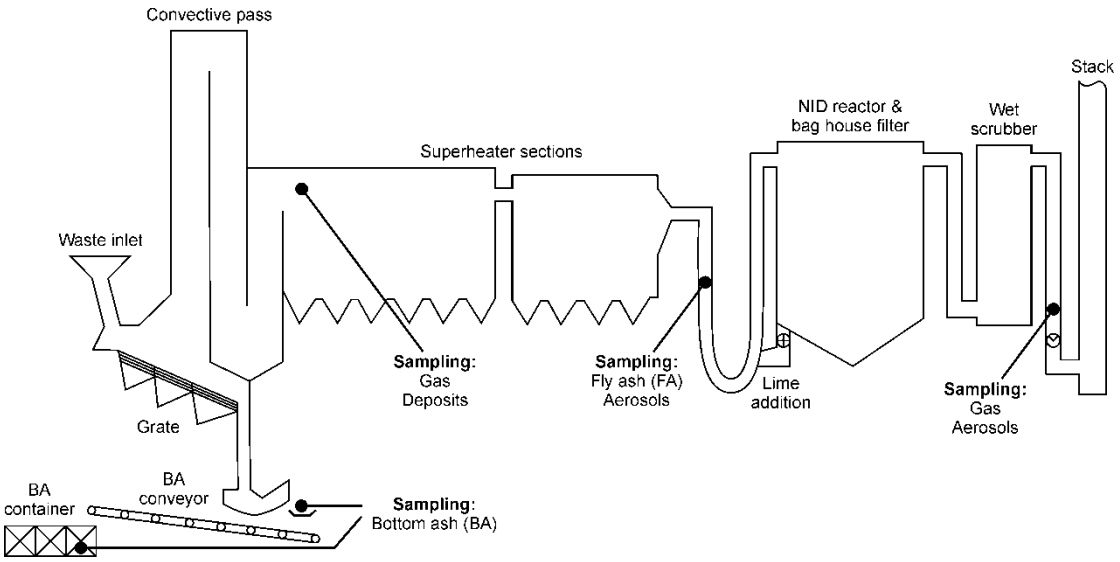


*Figure 1. Overview of the FASAN incinerator as well as gas and residue sampling points.*

Special attention was addressed to sampling of bottom ashes as these materials are highly heterogeneous. In the project an automated sampler was constructed and used to frequently take small samples from a falling stream of bottom ashes between two conveyer belts. During the course of one experiment (about 6-8 hours) typically about 40-60 small samples were acquired and combined into a single, primary sample of about 200 kg. This primary sample was sieved to remove large metal and inert objects above 20 mm (corresponding to about 10-15 % by weight), and reduced in size by a riffle sample splitter in order to obtain a lab sample of around 20 kg.

Prior to sampling and measurements mapping of system residence times (e.g. from input of the waste to output of the bottom ashes) were carried out by introducing batches of iron pipes in the waste hopper. All sampling and measurements were subsequently planned to accommodate various residence times of fly ashes and bottom ashes, and address the same specific waste input in the individual experiments, see Astrup et al. (**I)** for details.

## The FASAN experiments

In total 12 experiments were carried out: six with changes in waste input and six with changes in operational conditions, including one reference experiment.

### Changes in waste input

In experiments with changes in the waste input (experiments W1-W6) six waste material fractions were added one-by-one to the base-load waste (fraction per wet weight in parentheses):

- Road De-icing Salt (0.5 %)
- Shoes (1.6 %)
- Automobile Shredder Waste (14 %)
- Batteries (0.5 %)
- PVC (5.5 %)
- Chromate-Cupper-Arsenate Impregnated Wood (11 %)

*Table 2. Operational data collected during experiments (see Astrup et al. I and Pedersen et al. II for details). $O_2$ levels are average values downstream the boiler (% vol., wet). Temperatures are given at the bottom of the furnace (T1), top of the furnace (T2) and downstream the boiler (T3). .The air flows are given on a normalized basis (to the average of all experiments)*

| | Operational Conditions (OC) Experiments | | | | | | Waste Input (WI) Experiments | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ref | Undef. cond. | Min. O2 | Max. O2 | Dec. Sec. | Inc. Sec. | Salt | Shoes | Shredder waste | Batteries | PVC | Wood |
| $O_2$ level (vol.%, wet) | 7.3 | 8.3 | 7.2 | 9.1 | 7.9 | 7.5 | 7.6 | 8.0 | 7.5 | 7.9 | 7.9 | 7.8 |
| T1 ($^o$ C) | 1037 | 985 | 1018 | 991 | 1010 | 1011 | 1014 | 1011 | 1028 | 1017 | 1010 | 1018 |
| T2 ($^o$ C) | 865 | 928 | 912 | 890 | 912 | 1179 | 920 | 1124 | 919 | 963 | 1112 | 1024 |
| T3 ($^o$ C) | 175 | 173 | 176 | 184 | 175 | 175 | 175 | 177 | 175 | 176 | 175 | 176 |
| Primary Air | 0.90 | 1.08 | 1.00 | 1.15 | 1.14 | 0.78 | 1.03 | 0.92 | 1.01 | 1.14 | 0.91 | 0.93 |
| Secondary Air | 1.09 | 0.79 | 0.61 | 1.44 | 0.73 | 1.22 | 1.02 | 0.99 | 1.05 | 0.93 | 1.12 | 1.00 |
| Total Air Flow | 0.96 | 1.00 | 0.88 | 1.24 | 1.01 | 0.91 | 1.03 | 0.94 | 1.02 | 1.07 | 0.98 | 0.95 |
| Air distribution | 65/35 | 76/24 | 79/21 | 65/35 | 78/22 | 59/41 | 70/30 | 68/32 | 69/31 | 74/26 | 65/35 | 68/32 |

During these experiments, plant operational parameters were maintained as close as possible to standard values for the incinerator, and the LHV of the mixed waste was kept around 8-10 GJ/ton.

Prior to each experiment, a section of the waste bunker was prepared with alternating layers of base-load waste and the individual fraction used in the particular experiment, thereby allowing the crane grab to vertically cut through several layers at a time. This was done to ensure best possible mixing of the waste fractions with the base-load waste. Feeding was done at typical rates for the furnace (around 8-12 ton/hour). Between the experiments with changes in waste input, the furnace was fed with base-load waste only. The waste composition in these experiments is discussed in Chapter 2. Mass flows.

**Changes in operational conditions**

Six experiments were carried out with operational conditions outside normal operation (experiments OC1-OC6). The parameters changed were:

- Two experiments with changes in oxygen level: Minimum and Maximum $O_2$
- Two experiments with changes in air supply distribution: Decreased and Increased secondary air
- One reference experiment with standard furnace conditions ("Reference")
- One experiment in which the furnace showed unstable and incomplete combustion on the grate as an example of a worst case scenario ("Undefined conditions")

More reference experiments were planned but could not be completed within the timeframe of the experiments due to operational instabilities. During the OC experiments only base-load waste was fed to the incinerator. Table 2 outlines the experiments and experimental conditions.

Changes in operational conditions were done by changing appropriate "furnace set-points", i.e. sets of operational parameters that the control system and the operators seek to maintain. As it is not possible to completely fix furnace parameters, this approach allowed the operators to continuously make small adjustments to the

furnace exactly as during normal operation. Other changes than oxygen level and air distribution were originally planned but it was difficult during the experiments to maintain steady-state conditions at these alternative set-points. Consequently, the project focused on these two parameters. In all cases, changes to the operational conditions were attempted "as large as possible" while still being possible from a practical point of view.

**Solid samples collected**
During all 12 experiments at FASAN the following solid residue samples were collected:

- Fly ash particles sampled from the flue gas duct
- Bottom ashes sampled from the ash conveyer: "fresh"
- Bottom ashes same as above but carbonated in the lab: "lab-scale aged"
- Bottom ashes aged for 3 months at AFATEK's facilities in Næstved: "naturally aged"

It was not possible to representatively sample fly ashes after flue gas cleaning at FASAN as large quantities of fly ashes were kept in the bag filter for recycling purposes in the ALSTOM NID system. Due to an estimated residence time in the filter of 1-2 days, it was not possible to relate samples collected here to specific waste on the grate. Consequently, it was decided to focus on samples of fly ash particles taken from the flue gas duct. As these samples were only about 5-20 g per experiment, only a limited number of analyses could be carried out on fly ashes (and leaching experiments could not be done).

## Reference residue data

In addition to the residue samples collected during the FASAN experiments, a range of bottom ash and fly ash samples were collected from several Danish waste incinerators. Further, bottom ash data from regulatory compliance testing were supplied by a range of incinerators. The following samples and data were included in the project as a supplement to the FASAN experiments:

- One-year average fly ash and APC residue samples from: Amagerforbrænding, Nordforbrænding, KARA, Odense, Vestforbrænding, Århus (solid composition from Amagerforbrænding, leaching data for all)
- One-year average bottom ash samples from: Amagerforbrænding, Nordforbrænding, KARA, Vestforbrænding, Århus (solid composition, leaching data)
- Bottom ash samples over time (2006-2008): Amagerforbrænding and Århus (solid composition)
- Bottom ash leaching data over time (2006-2008) from regulatory compliance leaching tests: Amagerforbrænding, Nordforbrænding, KARA, Vestforbrænding, Århus, FASAN

Fly ash/APC residue and bottom ash samples were collected during the course of approximately one year for each incinerator within the period: 2006-2008. All samples consisted of a range of subsamples collected as grab samples from each

individual ash container or ash silo, e.g. collected during emptying of the silo or before transport of the container. All subsamples were then collected and mixed thoroughly. The mixed sample covering the entire year was finally transported to the lab and represented an "averaged one-year" sample for each incinerator. Due to limited possibilities for obtaining representative samples at some of the plants, not all of the planned ash samples could be obtained within the scope of the project.

The reference samples were characterized with respect to leaching in batch and column experiments and used for comparison with data from the FASAN experiments. The bottom ash leaching data covering a period of about two years as supplied by the incinerators were also used for comparison (see Hyks and Astrup **IV** for details). Additional ash samples collected over time for two Danish plants were characterized with respect to total content. These data as well as the leaching data were included in Appendix VII.

## Project dissemination

Two project workshops were carried out within the project period: one workshop before the FASAN experiments (June 2006) and one workshop towards the end of the project (April 2009). At both workshops, external stakeholders and interested parties from Danish companies, organizations, and public entities were invited.

At the first workshop, plans for the full-scale experiments and subsequent lab activities were presented, and approaches within the project discussed. At the second workshop, all major results were presented and discussed with the invitees. Suggestions for potential follow up activities were also discussed at the second workshop (see Chapter 6. Suggestions for further research).

In addition to the more detailed discussions at the workshops, project results and experiences have been presented at a range of Danish meetings (e.g. DAKOFA, DAFONET) as well as in relation with other research projects. Project results have further been presented at a number of international conferences:

- Astrup, T. (2008): Full scale test incineration of special waste fractions: residue quality and environmental aspects. Proceedings Venice 2008, Second International Symposium on Energy from Biomass and Waste Venice, Italy; 17-20 November 2008
- Riber, C.; Astrup, T.; Christensen, T.H. (2007): Second generation methodology for characterization of solid waste fractions. Sardinia 2007, Eleventh International Waste Management and Landfill Symposium, 1-5 October, S. Margherita di Pula (Cagliari), Italy.
- Pedersen, A.J.; Frandsen, F.; Riber, C.; Astrup, T.; Thomsen, S.N.; Lundtorp, K.; Mortensen, L.F.: A Full-Scale Study on the Partitioning of Trace Elements in Municipal Solid Waste Incineration – Effects of Firing Different Waste Types. 'IMPACTS OF FUEL QUALITY ON POWER PRODUCTION & ENVIRONMENT', September 29$^{th}$ – October 3$^{rd}$, 2008, Banff, Canada.
- Frandsen, F.J.; Pedersen A.J.; Hansen, J.; Madsen, O.H.; Lundtorp, K.; Mortensen, L. (2008): Deposit Formation in the FASAN WtE Boiler as a Function of Feedstock Composition and Boiler Operation. 'IMPACTS OF FUEL QUALITY ON POWER PRODUCTION & ENVIRONMENT', September 29$^{th}$ – October 3$^{rd}$, 2008, Banff, Canada.

- Pedersen, A.J.; Frandsen, F.J.; Astrup, T.; Riber, C.; van Lith, S.; Steinsen, S.D.; Holgersen, L.B. (2008): Partitioning of Trace Elements in a WtE boiler; The Influence of Different Waste Types. In: Proceedings from Twenty-Seventh Annual International Conference on Thermal Treatment Technologies, May 12-16, 2008, Montreal Quebec, Canada, Paper #35
- Pedersen, A.J.; Frandsen, F.J (2008): Partitioning of trace elements in a WtE boiler and the effects of different waste types. In: Proceedings from 235th American Chemical Society National Meeting and Exposition, April 6-10, 2008, New Orleans, Louisiana, USA.
- Pedersen, A.J.; Zeuthen, J.; Frandsen, F.; Livbjerg, H.; Hansen, J. (2007): Characterization of flue gas, fly ash, aerosol and deposit compositions as a function of waste composition and grate operation. In: Proceedings of the Twenty-sixth Annual International Conference on Incineration and Thermal Treatment Technologies : May 14-18, 2007, The Sheraton Crescent Hotel, Phoenix, Arizona, USA


## Collaboration with other projects

During the project period, the project partners have utilized the experiences gained in this project in relation to other Danish projects. In a number of cases, the project has collaborated with other projects on specific aspects related to the performed experiments. Examples of such collaboration are given below:

- PSO-7170: fly ash samples from the FASAN experiments were made available for this project for determination of dioxin levels. Further, log data from the FASAN experiments were supplied in relation to a dioxin formation model developed in this project. At the time of writing no results were available from these activities.
- CHEC consortia (ITOB - CHEC Industrial Consortium on Thermal Conversion of Fuels): this project installed deposit probes in the boiler section during the FASAN experiments (Reported in Frandsen et al. **V**). The CHEC consortia also conducted laboratory scale release experiments on waste fractions from FASAN.
- Several projects with Danish waste incinerators on residue quality and leaching: experiences gained in relation to the FASAN experiments have been used for designing and evaluating experiments in other projects, and results from PSO-5784 have been used as a reference for comparison in several other projects.

# 2. Mass flows

## Mass and energy balance calculations

The composition of the waste input cannot be determined directly in a simple manner (e.g. digestion of solid samples) due to the heterogeneity of mixed waste; however, the composition may be determined indirectly based on mass and water balance calculations combining the outputs from the incinerator to obtain the input (the waste) assuming mass conservation in the system. This approach has been discussed by several authors and has been applied in several cases on waste incinerators (Astrup et al. **I**).

In this project the system boundaries for the mass balances included the waste input (waste hopper) to the sampling of fly ash particles and bottom ashes (see Figure 1): outputs were fly ashes (including aerosols), flue gas, and bottom ashes, while the input was the waste. In the following overall substance balance (BA: bottom ash, FA: fly ash), M denotes masses while C denotes element concentrations:

$$M_{waste} \times C_{waste} = M_{BA} \times C_{BA} + M_{FA} \times C_{FA} + M_{flue\ gas} \times C_{flue\ gas} \quad (1)$$

Masses were recalculated into dry basis to account for variations in water content of the input waste. This was done based on a water balance for the furnace system using data for moisture in the gas phase and water flows in the plant; only the water content in the waste input was estimated. This was done by assuming all H in the waste was oxidized to $H_2O$ in the furnace (Astrup et al. **I**).

## Waste composition

The composition of the base-load waste was determined using equation (1) as an average of the waste compositions during experiments with changed operational conditions (OC1-OC6), see Table 3. As the mixing and preparation of the base-load waste was kept as stable as possible during experiments, the variations observed in waste composition during the operational experiments may be regarded as "typical" variations for this incinerator during normal operation. Worth noticing is the observed standard deviation of the composition data: for many elements this is one order of magnitude below the average value. This is rather accurate considering the relatively large heterogeneity of solid waste.

To assess whether the addition of special waste fractions was reflected by the overall waste compositions in experiments with changed waste input (W1-W6), we used the criteria that calculated element concentrations in the individual waste fraction should be higher than the mean value plus two times the standard deviation of the base-load waste (OC experiments). This approach allowed us to identify those elements which were most likely present in high concentrations in the waste fractions compared with the base-load waste. Table 3 shows the affected elements for each experiment, including the calculated element concentrations.

*Table 3. Chemical composition of the base-load waste and the individual waste fractions (see Astrup et al. I for details). Data for the individual fractions are per weight of the fractions. All data are in g/tonne of waste.*

| | Base-load waste | | Waste fractions | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Average | Standard Dev. | Salt | Shoes | Shredder | Batteries | PVC | Wood |
| As | 11 | 2.0 | | | | | | 400 |
| Ba | 480 | 320 | | | 6,200 | | | |
| Cd | 6.3 | 2.2 | | 250 | | 480 | 120 | |
| Cl | 15000 | 1400 | 1,100,000 | 230,000 | | | 410,000 | |
| Co | 13 | 8.1 | | | | 2,200 | | |
| Cu | 2600 | 1900 | | | 26,000 | | | |
| Fe | 22000 | 11000 | | | 170,000 | | | |
| Hg | 0.33 | 0.14 | | | | 240 | | |
| K | 4300 | 510 | | | | | | 9,800 |
| Mn | 330 | 100 | | | 1,600 | | | |
| Mo | 5.1 | 3.1 | | | 48 | | | |
| Na | 11000 | 1600 | 230,000 | | | | | |
| Ni | 110 | 76 | | | 1,100 | | | |
| Pb | 570 | 200 | | | 2,900 | | | 6,900 |
| S | 3500 | 760 | | | | 120,000 | | 34,000 |
| Sb | 45 | 23 | | | 260 | | | |
| Si | 62000 | 7200 | | | | | | 140,000 |
| Sn | 48 | 33 | | | 640 | | | |
| Sr | 130 | 33 | | | | 5,200 | | |
| V | 14 | 4.4 | | | 60 | | | |
| Zn | 1600 | 450 | | | 19,000 | | | |

Salt was as expected contributing with considerable quantities of Na and Cl. The calculated Cl content appeared to be slightly above 1 kg/kg clearly indicating that these data should be used with caution, especially in the cases Salt and Batteries. These two waste fractions were added in particular low concentrations (0.5 % w/w) relative to the base-load waste thereby indicating that a higher uncertainty would be associated with the calculated waste composition (i.e.. the lower input level of the specific waste fraction, the lower the accuracy of the indirectly calculated chemical composition). Similar considerations should be addressed elements present only in small concentrations likely associated with specific waste materials: the most important example is Hg in batteries which is likely also affected by the relatively low input level (0.5 %). In conclusion, although the waste compositions listed in Table 3 are considered state-of-the-art the data should not be used un-critically.

Our primary focus was to identify which elements appeared to be enriched in the individual waste fractions. By evaluating differences in calculated element concentrations between the individual experiments, it can be seen that the waste fractions likely contributed with specific elements. Shoes were adding Cd and Cl to the waste mix. Shredder Waste contributed with a range of metals likely originating from small pieces of metals in the waste fraction. Batteries appeared to contribute with high amounts of Cd, Co, Hg, S, and Sr relative to the base-load waste. PVC Waste contributed with Cd and Cl, while Impregnated Wood added As, K, Pb, S, and Si. In conclusion, it appeared that the experiments with different waste fractions significantly altered the waste input composition of both heavy metals, organic and inorganic Cl.

## Residue composition and element distribution

Evaluating the consequences for the solid residues, it is necessary to account for the concentration levels in the actual ashes as well as the amount of an element routed to the individual ashes. In Figure 2 and 3, element concentrations in bottom ashes and fly ashes are shown as a function of the fraction of the input found in either of the ashes. Relating these data to the amount of an element fed in with the waste can provide information about to which extent the solid residues were affected by the changes induced in the experiments. In the figures, error bars indicate two times the standard deviation around the mean of the OC experiments. Based on this, it was assessed whether the variations were likely caused by fluctuations in operational conditions rather than changes in waste input (Astrup et al. **I**).

As was the case for the chemical compositions of the individual waste fractions a certain uncertainty may be associated with the results. However, the compositional data for the residues produced during the experiments (y-axis in Figure 2 and 3) are significantly more accurate as these data are determined by actual measurements on the ashes themselves. The fraction of the input distributed in the bottom or fly ashes is on the other hand based on the previously mentioned mass balance calculations and are therefore less accurate. The use of error bars as described above in the interpretation of the results acknowledges this inherent uncertainty.

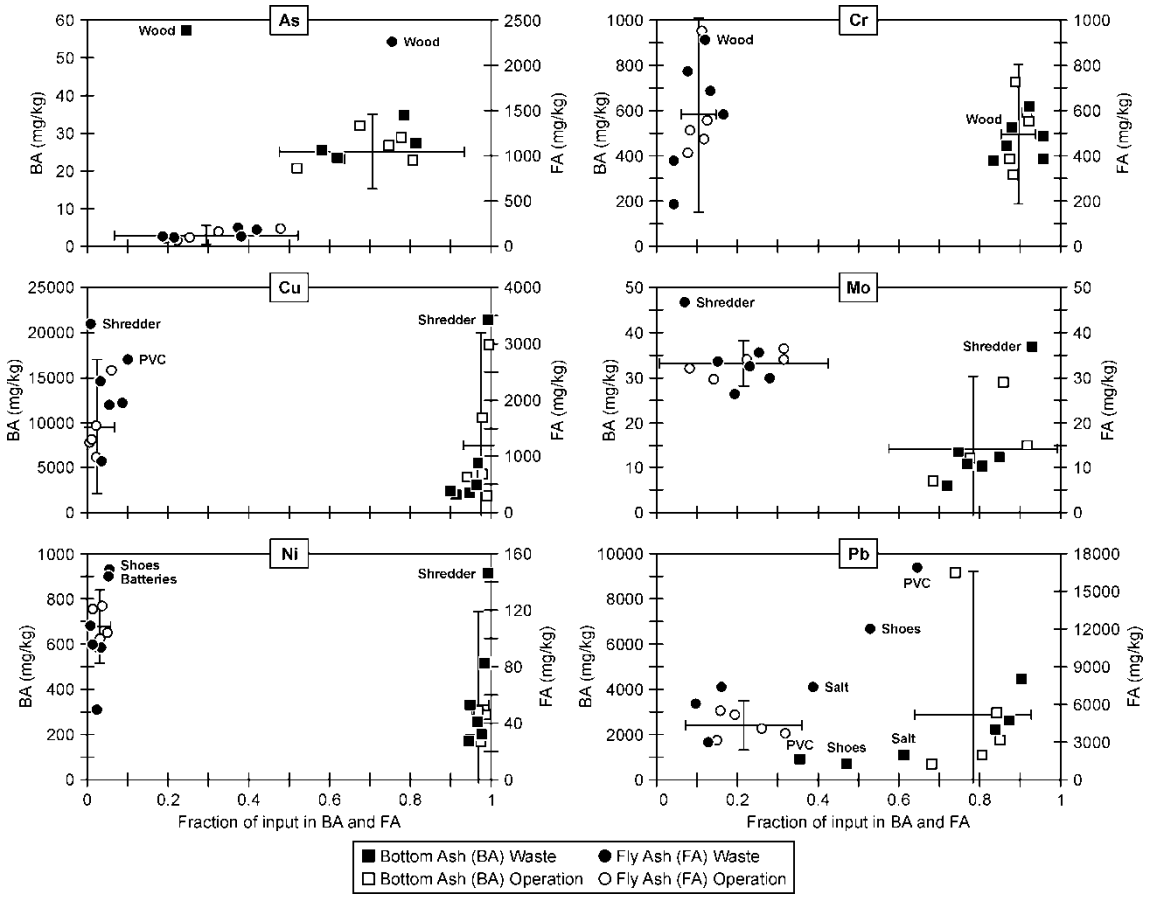


*Figure 2. Concentrations of As, Cr, Cu, Mo, Ni, and Pb in bottom ashes and fly ashes as a function of the fraction of the elements in the individual ash samples. Error bars indicate two times the standard deviation of samples from the operational experiments (see Astrup et al. I for details).*

**As, Cr, Cu, Mo, Ni, and Pb**

Generally, most of As, Cr, Cu, Mo, and Ni was found in the bottom ashes. Generally, the variations observed in solid contents due to changes in waste input appeared to be "covered" by the variations observed in the OC experiments. This indicated that the effects from changes in waste input were less or equal to what can be expected from changes in operational conditions.

More than half of As was found in the bottom ashes however in the Impregnated Wood experiment only 20 % of As ended here. Data for the OC experiments generally covered the variations observed for As concentrations during experiments with waste input changes, except in case of Impregnated Wood where both bottom ashes and fly ashes had considerable higher concentrations. More than 80 % of Cr was found in the bottom ashes. The operational experiments generally "covered" the variations in ash concentrations in the waste experiments indicating that Impregnated Wood did not have a significant effect on Cr although this was the case for As.

Cu and Mo were mostly found in the bottom ashes and the observed variations appeared to be covered by variations in the OC experiments; however, combustion of Shredder Waste resulted in significantly higher ash concentrations for both elements, and also higher Mo fraction in the fly ashes. This corresponded with high input levels of these elements in Shredder Waste. Ni was almost entirely found in bottom ashes with elevated concentrations in the Shredder Waste experiment, again corresponding well with high input levels and the possibility of metallic Ni in Shredder waste being likely to stay in the bottom ash. The fly ashes also showed increased Ni concentrations in the Shoes and Batteries experiments; however, this could not be related to significantly higher input levels as determined for these experiments, although Ni is a known constituent of batteries. In the Salt experiment, significantly lower concentrations were observed in the fly ashes although this could not be correlated with a lower input of Ni.

For Pb a more diverse pattern was observed. Although Pb mostly appeared to be favored in the bottom ashes a few experiments showed higher fractions in the fly ashes (increasing order: Salt, Shoes, PVC). The experiments indicated that (organic bound) Cl had a mobilizing effect on Pb (Pedersen et al. **II**). This is further discussed in Chapter 3.

Relating the above to waste composition data in Table 3, it is seen that while increased concentrations of As, Cu, and Mo coincided with waste fractions having high contents of the same elements, increased concentrations of Cr, Ni, and Pb could not be fully explained with higher input levels. This indicated that the waste mix was important and that other constituents and mechanisms controlled ash concentrations such as the case with Cl affecting Pb concentrations.

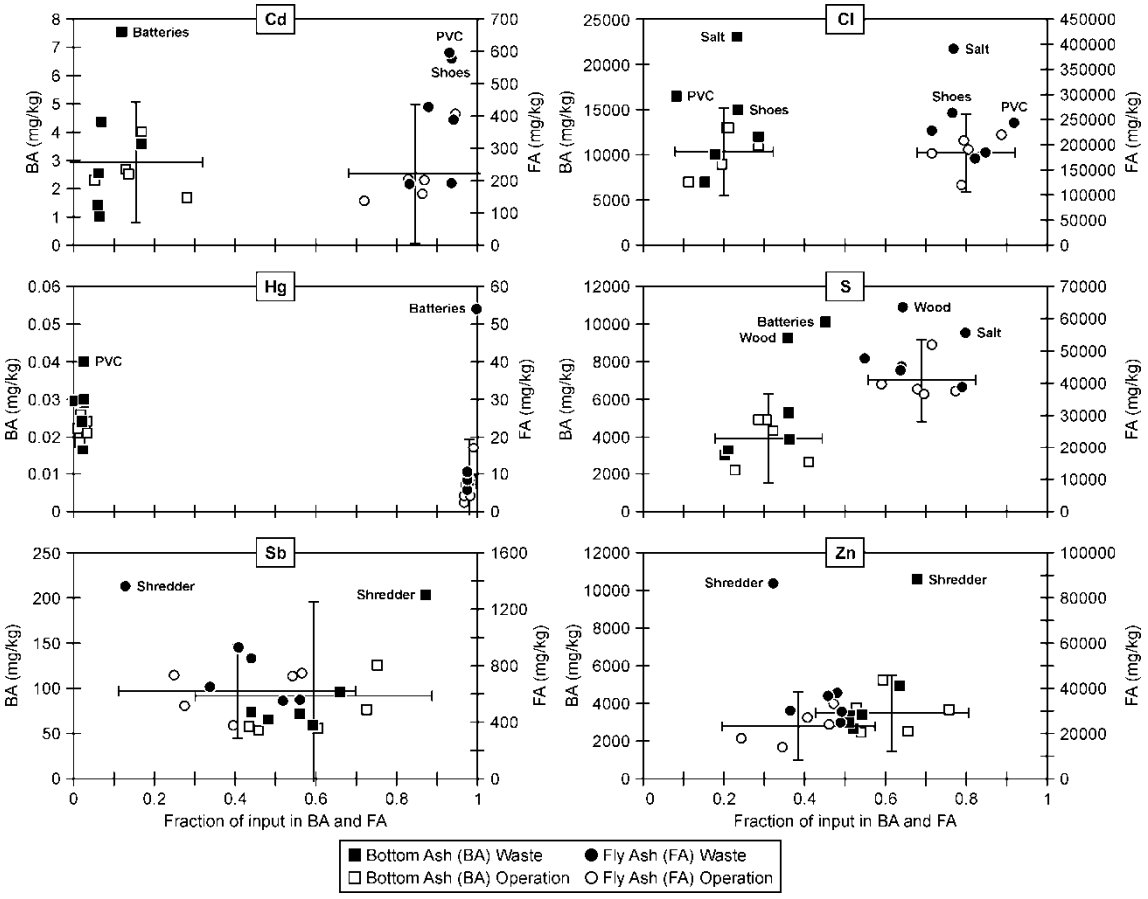


*Figure 3. Concentrations of Cd, Cl, Hg, S, Sb, and Zn in bottom ashes and fly ashes as a function of the fraction of the elements in the individual ash samples. Error bars indicate two times the standard deviation of samples from the operational experiments (see Astrup et al. I for details).*

**Cd, Cl, Hg, S, Sb, and Zn**

Cd was mostly found in the fly ashes. The concentrations were generally covered by the variations observed in the OC experiments; however the fly ashes had higher concentrations in the PVC and Shoes experiments and the bottom ashes higher concentrations in the Batteries experiment. This corresponded well with Cd also being present in high levels in PVC, Shoes, and Batteries. Zn concentrations were within the variations found in the OC experiments, except for Shredder waste where both ashes had significantly higher concentrations. This corresponded with Shredder waste being significantly enriched in Zn compared with the base-load waste. Sb concentrations were also within variations in the OC experiments except for the Shredder waste which was enriched with Sb.

Hg was almost entirely found in the fly ashes and the gas phase with relatively small variations (generally covered by the operational experiments); however feeding Batteries caused significantly higher Hg concentrations in the fly ashes/gas phase (Astrup et al. **I**). This behavior corresponded well with Batteries contributing with high levels of Hg indicating that batteries may be a significant Hg source in combustible waste.

High Cl concentrations in the Salt, PVC, and Shoe experiments (declining order) were observed in the bottom ashes, and high Cl concentrations in the Salt and Shoes experiments (declining, PVC third highest) were observed for fly ashes. This

corresponded with increased Cl levels found in these waste fractions (see also Chapter 3, Flue gas/particle partitioning).

S was found primarily in the fly ashes and the gas phase (> 50 %). S concentrations were generally covered by the OC experiments; however Salt and Impregnated Wood caused higher concentrations in the fly ashes, and Batteries and Wood caused higher concentrations in the bottom ashes.

## Stack emissions

To evaluate how the flue gas cleaning system reacted to the changes in waste input and operational conditions, standard measurements were carried out on the clean gas prior to the stack. Selected clean gas concentrations (As, Cd, Cr, Hg, Pb, and Sb) are discussed below.

Generally, the gas cleaning system maintained low As emissions but when combusting Impregnated Wood the emissions increased significantly which corresponded with the higher As load in this experiment. Cd emissions appeared to remain below 7 mg/tonne waste, except in the Undefined Conditions experiment and when incinerating Batteries (about 5 times the average of the others). The higher emission in case of Batteries corresponded with Cd being enriched in the Batteries fraction. Batteries also resulted in significantly increased emissions of Hg, likely due to the presence of Hg in coin cell batteries. Hg is generally very volatile and appeared in the Battery experiment to be almost entirely found in the gas phase without being captured in the flue gas cleaning system. Cr showed slightly increased concentrations for Impregnated Wood (about double the average of the others). Although this did not appear significant in the mass balance calculations, Cr should be present in the Impregnated Wood due to the use as fixation agent in the treatment process. In case of PVC, Sb appeared significantly increased in accordance with the potential presence of Sb as stabilizer in PVC (although this was not apparent from the mass balance calculations).

Pb was an example of an element not showing increased emissions despite increased load in the input waste, e.g. the Wood experiment. Emissions of Cu, Ni, and Zn were also not clearly correlated with input levels. Pb emissions for Undefined Conditions were generally found in the high end of the range (in case of Pb the highest value). This may indicate that poor combustion on the grate may lead to increased air emissions.

Overall, the stack emissions appeared to be strongly affected by the waste input composition. Although the flue gas cleaning system could effectively maintain low emission levels over a wide range of operational conditions, the potential influence from the waste input could not be ignored and extreme input levels resulted in increased air emissions. In particular, the results indicated that contents of PVC, impregnated wood, and batteries in the waste input should be limited.

## Implications for residue quality

As indicated in the previous sections, it was not possible to significantly determine correlations between specific changes in operational conditions and residue quality. This does not necessarily indicate that such correlations do not exist; it merely indicates that it was not possible to meaningfully ascribe the observed variations in residue quality to the specific operational changes implemented during the full-scale

experiments carried out at FASAN. A main reason for this is likely the complex and dynamic properties of a full-scale furnace which makes it difficult to control the combustion conditions throughout the waste bed and ensure that the operational changes have the anticipated effects. The operational changes implemented at FASAN were, however, done as "large as possible" within the capabilities of the furnace, i.e. without significantly hindering combustion on the grate. The operation during these experiments was significantly "outside" normal operation. This means that for the specific furnace, it is unlikely that operation at normal conditions will be "outside" what was tested during the experiments. It was therefore concluded that the operational changes included in the project would most likely bracket normal operation at FASAN, and that the residue qualities observed during these experiments therefore represented a range which would cover most situations.

The fact that significantly changed operational conditions did not result in discernable effects on the residue quality while significant changes in waste input appeared to have much more dramatic effects on the residues is an important observation. This indicate that the residue quality may be relatively robust with respect to furnace operation, or in other words that the changes in furnace set-points do not have such a dramatic effect on the residues.

In the project, the ranges in residue compositions observed for the OC experiments were in accordance with the above used as a basis for comparison with the experiments with changes in waste input (i.e. Figure 2 and 3). As the changes in waste input generally induced considerably larger changes in the residue quality than changes in operational conditions, it was concluded that the potential for optimizing residue quality were also larger when based on changes in the waste input. Consequently, it was concluded that focus should be put on the waste input composition rather than attempting to change furnace operation.

Combining the results for residue quality with the measured stack gas emissions, it appear that in particular the quantities of PVC, impregnated wood, shredder waste and batteries were important for the emission outputs from the incinerator. It is therefore likely that overall emissions can be reduced if these waste materials are excluded from the input to the incinerator. As these materials (in principle) are easily identifiable, a considerable potential for improvement of the environmental performance of waste incinerators may exist if the materials can be properly separated from the mixed waste input.

## Implications for environmental assessments

The full-scale experiments at FASAN clearly showed that both air emissions and residue qualities were significantly affected by changes in waste input composition but also to some extent changes in operational conditions, in particular in case of the residues. The experiments, however, also documented that modern flue gas cleaning systems may cope with substantial changes in waste input and still maintain relatively stable emissions levels for heavy metals. Although no clear correlation with changes in operational conditions were apparent, even worst-case conditions (in-complete burnout) did not appear to significantly affect emissions and element flows.

The presented results are important because authority approvals for incineration of specific waste materials generally assume business-as-usual performance of the incinerators. The experiments illustrate that specific waste materials may dramatically affect air emissions and change element flows. These aspects are important for environmental performance evaluations, e.g. life-cycle

assessments. Traditionally such assessments have been based on fixed sets of emissions and element flows irrespectively of the waste input. It is suggested that more accurate results can be obtained when changes in air emissions and residue composition are taken into account. It is recommended that results of environmental assessments involving waste incineration should be thoroughly tested with respect to the variations in output data reported in this paper.

# 3. Flue gas/particle partitioning

## Overview

The main objectives relative to the flue gas/particle phase partitioning study was to improve the understanding of the formation of fly ashes in waste-fired boilers. In this context, the experimental data from FASAN on particle and gas phase compositions (metals, salts) in the boiler/flue gas duct system were analyzed thoroughly. Special focus was on the elements: Na, K, S, Cl, Zn and Pb, corresponding to the six major elements by weight found in the aerosols, and the elements considered most important with respect to corrosion and deposition aspects in waste fired boilers. Besides being highly volatile, chlorides of the alkali metals Na and K, as well as the heavy metals Zn and Pb, are the species thought to be the most chemically aggressive and the ones primarily responsible for corrosion. The heavy metals facilitate corrosive reactions by forming low melting-point mixtures (eutectics) with alkali chlorides in the deposits on metal surfaces.

In addition to the evaluation of the experimental data, a model aiming to predict the gas/particle phase partitioning in the flue gas channel as a function of time and temperature was developed: A physical model for heterogeneous condensation (i.e. surface condensation on existing particles) of trace elements on a size distributed fly ash was developed and coupled with an existing global equilibrium analysis model.

## Sampling positions and methodology

During the different full-scale experiments at FASAN, samples of flue gas, fly ash, aerosols and deposits were taken at three different locations in the boiler, as indicated in Figure 1. The results from the flue gas measurements are reported in details in Zeuthen et al. (**III**) (aerosol measurements), Pedersen et al. (**II**) (fly ash measurements and over-all flue gas/particle partitioning) and Frandsen et al. (**V**) (deposit measurements).

The major flue gas components (CO, $CO_2$, $O_2$, $SO_2$, NO) were monitored continuously at a sampling location in the top of the furnace (see Figure 1) using a gas extraction probe and standard gas analyzers. The initial deposit formation was also measured at this location. Air-cooled probes were applied to collect deposits on and inside the boiler. In the standard set-up, the deposition probe was operated with a surface temperature of 400 $^{o}$C, in order to simulate the current steam temperature in the final superheater of the FASAN plant.

Fly ash (total dust) and aerosols were sampled in the flue gas duct downstream of the boiler, but upstream of the flue gas cleaning (NID) reactor and bag filter (see Figure 1). A probe for sampling of fly ash (total dust) from the hot flue gas by isokinetic extraction was developed at CHEC for the present campaign. The sampling of fly ash served two main purposes: (1) to find the total dust load during the different experiments, and (2) to collect samples for further analyses. Approximately 20 g of particulate material was collected from each experiment (minimum fly ash sampling time 1.6 h per experiment).

The measurements of mass-based size distributions of aerosols were made using a 10-stage Berner Low-Pressure Cascade Impactor (LPI), and number-based

size distributions were obtained using a Scanning Mobility Particle Sizer (SMPS). Both aerosol measurement methods (LPI and SMPS) give information on the particle size distribution of the aerosols (mass based and number based, respectively), and the LPI method also allows for chemical analysis of the deposited aerosols by means of e.g. SEM/EDX. Additional SMPS measurements were made on the cleaned flue gas in the stack.

## Dust and aerosol loads

The total dust load, as found by the fly ash sampling method, was varying between 1.8 and 2.8 g/m$^3$ (std. T,P) in most experiments, with an average of 2.2 g/m$^3$ (std. T,P) and no apparent correlations to the operational conditions or waste input composition (Pedersen et al. **II**). The particle size distribution of the total dust samples, as measured by laser diffraction, revealed a bimodal size mode with a peak below 5-10 µm (fine mode) and a second peak at app. 100 µm (coarse mode). The particle size distribution tended to change towards finer particles when firing NaCl salt, indicating increased (homogeneous) condensation of alkali salts in this experiment (Pedersen et al. **II**).

The mass-based aerosol size distribution revealed a peak around 0.4 µm (see Figure 4). The aerosol mass-load was very stable when no changes in fuel composition were introduced ($PM_{2.5}$: 252 ± 21 mg/m$^3$) and increased significantly during combustion of waste when including automotive shredder waste, CCA-impregnated wood, and NaCl ($PM_{2.5}$: 313, 320, and 431 mg/m$^3$). The number concentrations of particles varied during combustion and between varying operational conditions and waste mixes (from $43 \cdot 10^6$ to $87 \cdot 10^6$ #/cm$^3$). The mass of the $PM_{2.5}$ fractions (252 mg/m$^3$) amounts to approximately 10 % of the total particle mass (Zeuthen et al. **III**).

The mass-based particle size distribution for reference conditions, the PVC experiment, and the salt experiment, respectively, is illustrated in Figure 4.

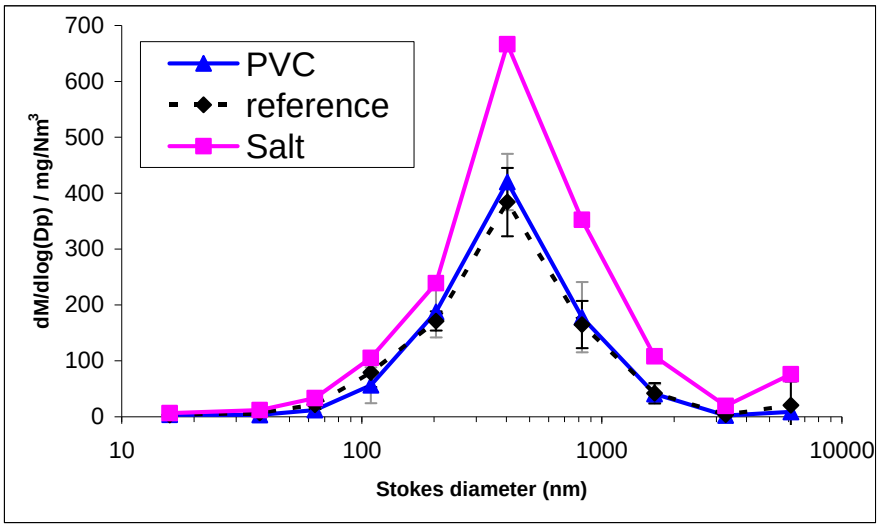


*Figure 4. Mass-based size distributions for aerosols from reference, PVC and Salt experiments, respectively. Meassured with cascade impactor.*

The increased mass load of fine particles when adding salt was not found when adding PVC, in spite that in both cases high amounts of chlorine was added. However, the chlorine in PVC was not bound in the particles, probably due to lack of alkali metals or other condensable cations. The chlorine in this case was released as HCl(g).

## Characterization of fly ash, aerosols and deposits

### Chemical composition of fly ash and aerosols

A complete chemical analysis of the fly ash samples from the FASAN measuring campaign, as analyzed by wet chemical techniques, is presented in Appendix **VII** (Table VII-1).

Detailed results for selected, volatile elements (Na, K, S, Cl, Zn and Pb) is presented and discussed in Pedersen et al. (**II**) and summarized here. Figure 5 illustrates the concentrations of these elements in the fly ash samples from the experiments adding different waste fractions, relative to the concentration in the fly ash from the reference experiment. For comparison, it was found that for the experiments with changes in grate operation parameters, the variations in concentration of the target elements were less than 50 % relative to the reference run (i.e. $< \pm 0.5$ relative concentration).

Figure 5 reveals a significant increase (> 100 %) in the concentration of an element in the fly ash in the following cases: Pb when firing PVC and shoes, Zn when firing shredder waste, and, Na and Cl when firing salt. For the salt experiment, the Na and Cl actually accounted for more than 80 % (w/w) of the total mass of the fly ash, as compared to less than 40 % in the reference experiment (and most other experiments).

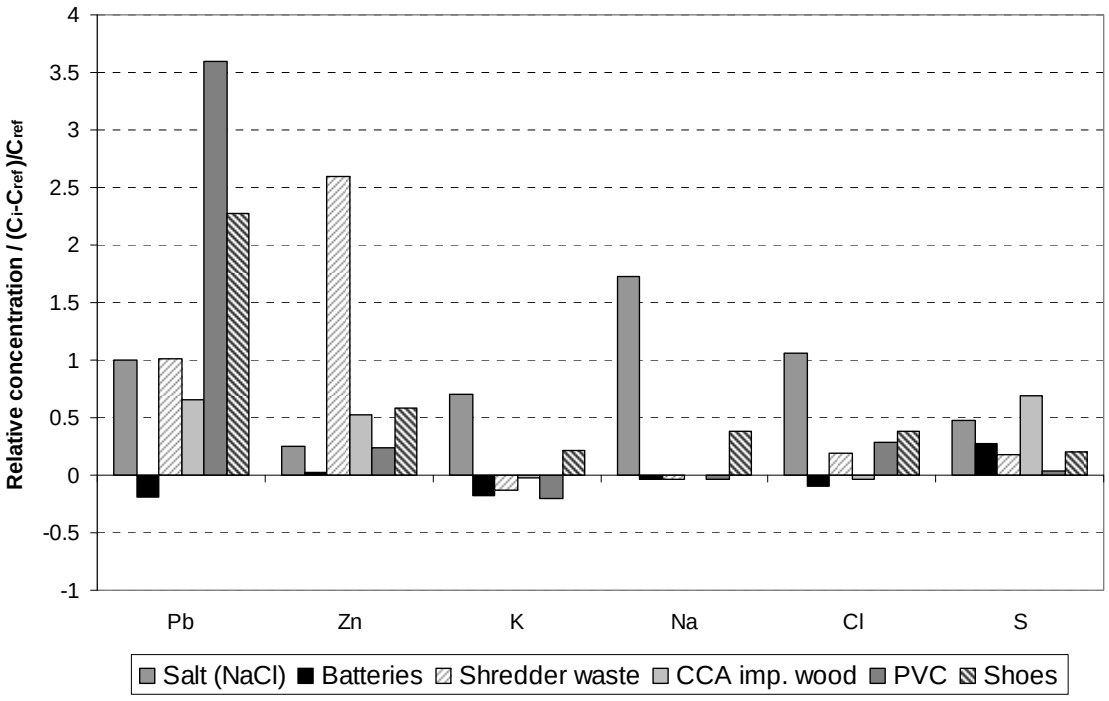


*Figure 5. Concentration of target elements (Pb, Zn, K, Na, Cl, S) in fly ash samples from "dedicated waste" experiment relative to reference conditions (Pedersen et al. **II**).*

The following elements were increased slightly (50 - 100 %) in concentration: Pb when firing shredder waste, salt, and CCA-impregnated wood, Zn when firing shoes and CCA-impregnated wood, K when firing salt, and, S when firing CCA-impregnated wood. Relating Figure 5 to Table 3 reveals that the variations found in the fly ash compositions only in some cases coincide with high input concentrations in waste fractions. This is further discussed later on, in the "partitioning of volatile elements" section, and in Pedersen et al. **II**.

The chemical composition of the aerosols from the experiments with different waste fractions added is illustrated in Figure 6. Only the experiments with changes in waste composition were investigated, as the operational conditions were not expected to influence the composition considerably. For each measured element the content is depicted for all 6 experiments with changes in fuel composition together. Details on more metals are provided in Zeuthen et al. (**III**).

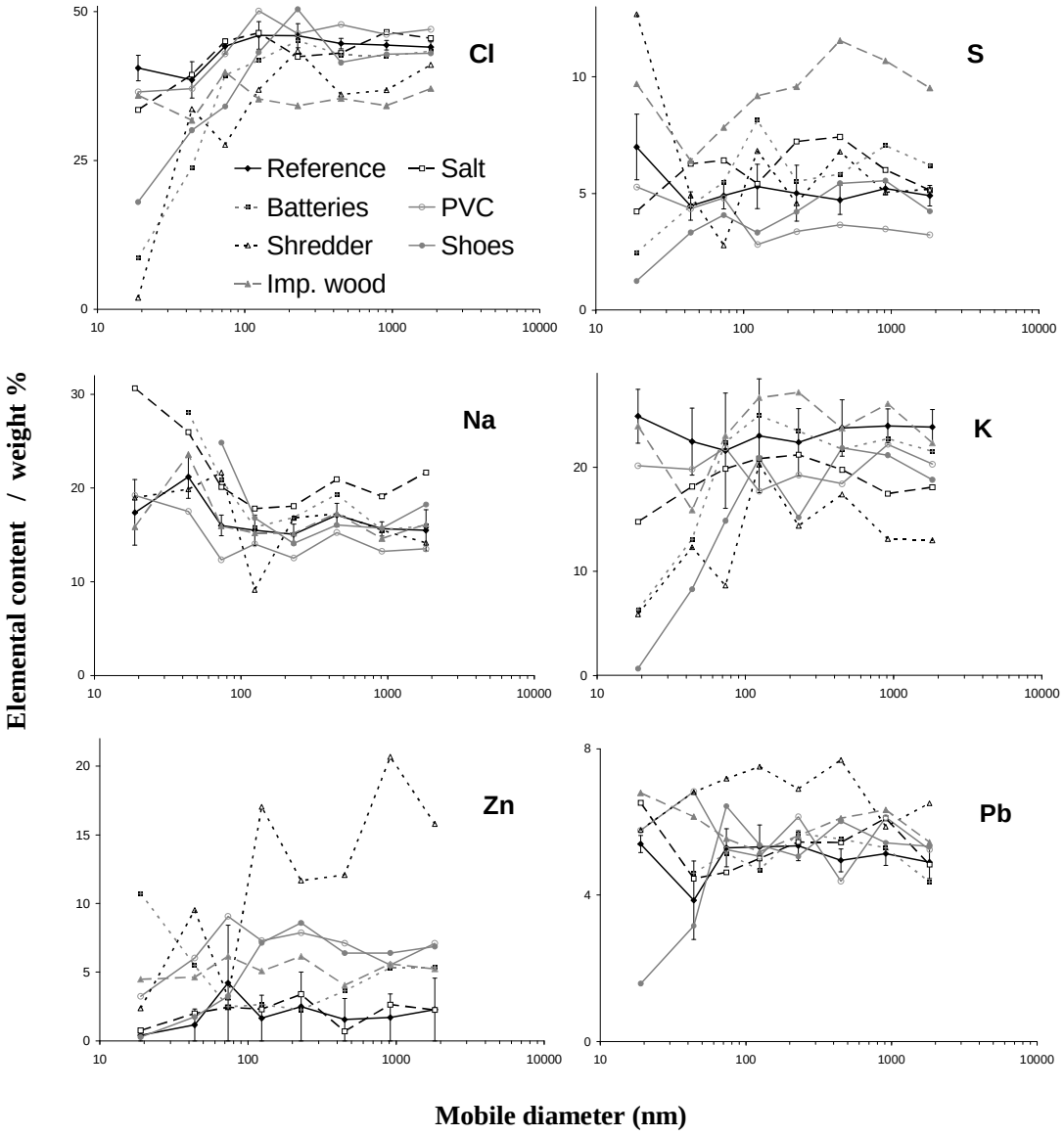


*Figure 6. Size dependent elemental content of main components of the combustion aerosols in experiments with addition of special waste fractions (Zeuthen et al. **III**).*

In all experiments the six major elements in the aerosols by weight were Cl, Na, K, S, Zn and Pb. The chlorine content was increasing with the particle diameter. The content of alkali (Na + K) was rather constant for all experiments. The molar Na/K ratio decreased with the particle diameter indicating that the sodium salts condenses at higher temperatures than those of potassium. The ratio was increased significantly when adding salt (+ 67 %) or shredder waste (+ 112 %) to the base-load waste. For shredder waste this increase was also due to very low K content in the particles. The Zn content increased with particle diameter, and for the experiments with shredder waste, shoes, PVC and impregnated wood the content was increased significantly. For the shredder waste experiment the content by weight was increased more than seven times with respect to Zn. The content of Pb was rather constant as a function of particle diameter and throughout the series of experiments. However, for the shredder waste combustion a 40 % increase was found.

**Deposit formation**

The deposit study (Frandsen et al. **V**) indicated that the grate operation did indeed affect the chemical composition and extent (i.e., the flux: g deposit/area/time) of deposit formation significantly.

The experiment with minimum addition of primary air, that is, maximum addition of secondary air, showed a significantly higher upstream deposition flux at a surface temperature of 400 $^{o}$C, see Frandsen et al. **V** for details. The primary air is let in through the grate, from below, while the secondary air is partly blown downward against the grate, through furnace top nozzles. Thus, a minimum of primary air would expect to give a lesser lift of particles from the fuel bed, but then the jets of secondary air may blow up particles from the top of the fuel bed, thereby more than compensating for the lack of lift from below.

The experiments with “undefined conditions” and “minimum $O_2$” in the flue gas gave significantly lower Cl in the deposits, compared to the rest of the operational conditions (Frandsen et al. **V**). This is an important feature from a material and corrosion point of view.

The addition of PVC and shoes to the base-load waste caused significantly increased deposition fluxes, and increased (not surprisingly) the concentration of Cl in the deposit. In contradiction, shredder waste and CCA impregnated wood caused lower Cl in the deposits (Frandsen et al. **V**).

## Partitioning of volatile elements

The partitioning, that is, the distribution of the elements between bottom ash, fly ash, aerosols and gas phase in the boiler, was studied for the target elements Na, K, Cl, S, Zn, and Pb (Pedersen et al. **II**).

The partitioning study suggested that the vaporization/condensation behavior of some elements was influenced by changes in feedstock composition, as there was not necessarily a correlation between the input concentration of an element in the feedstock, and the amount of the element recovered in the fly ash and flue gas fractions.

The study indicated that Cl and S play an important role for the partitioning of Pb, and maybe also Zn. When firing Cl-rich waste fractions (PVC, salt, shoes), the partitioning of Pb seemed to shift towards increased vaporization (and subsequent recovery in fly ash and aerosol fractions), whereas an opposite effect (decreased vaporization) was seen when firing S-rich waste fractions (CCA impregnated wood

and batteries). The effect, which was explained by the formation of volatile Pb-chlorides at high Cl concentrations, and stable Pb-sulphates at high S concentrations, is illustrated in Figure 7.

The partitioning study also implied that organically bound Cl (as in PVC, shoes) was preferably released (as HCl(g)) to the gas phase, whereas the inorganically bound Cl (salt) was recovered in the bottom ash and fly ash fractions (indicating alkali-chloride bonding), see Figure 8. This is in consistency with the findings from the aerosol study described earlier in this Chapter.

The results for overall-partitioning of alkali metals, Zn and S were less conclusive, probably because the changes induced by adding specific waste fractions were not big enough to cause significant changes in the over-all picture.

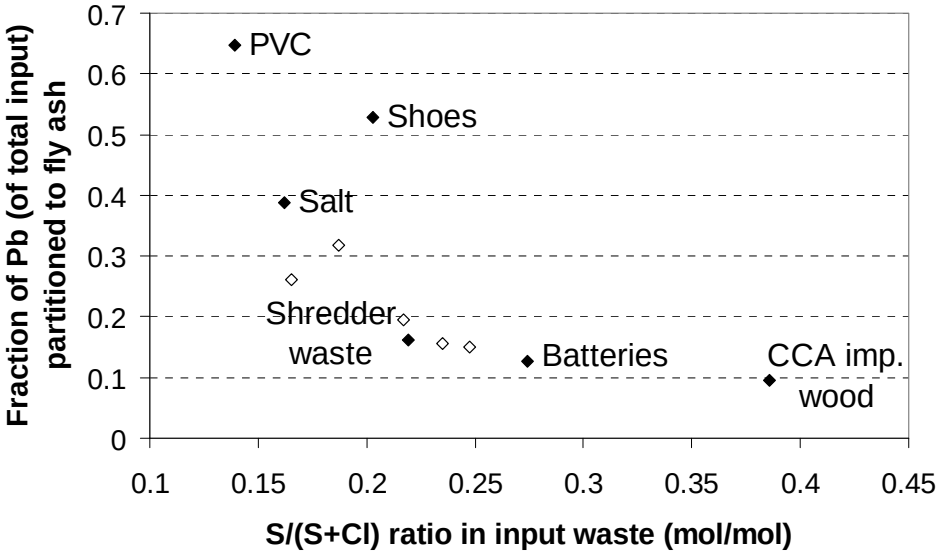


*Figure 7. Pb partitioning to fly ash as function of S/(S+Cl) ratio in input waste. Black marks indicate "dedicated waste" experiments, open marks indicate "base-load waste" experiments (Pedersen et al. II).*

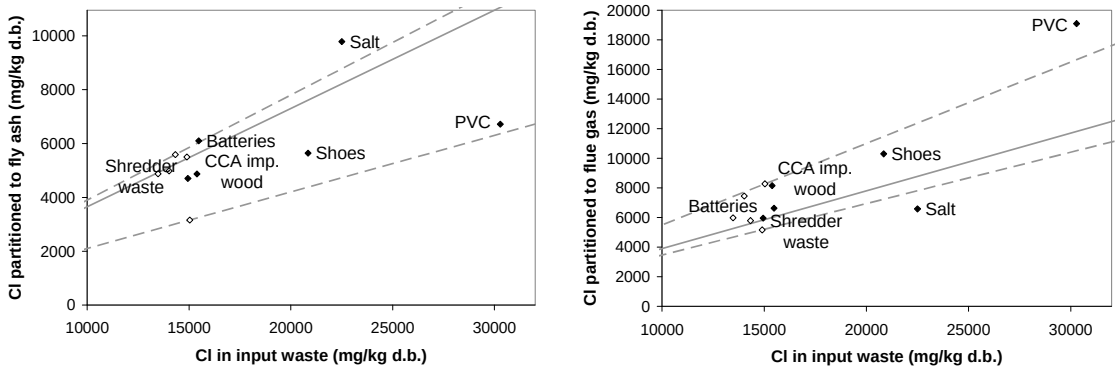


*Figure 8. Cl partitioned to fly ash and flue gas as function of input concentration (mg/kg input waste, dry base). Black marks indicate "dedicated waste" experiments, open marks indicate "base-load waste" experiments. The dotted lines indicate the upper and lower values for base-load conditions (Pedersen et al. **II**).*

**Link to laboratory-scale release results**

Lab-scale release experiments have been conducted on a number of dedicated waste fractions from the FASAN campaign, in order to understand the release pattern and the link to formation of fly ash and aerosols in full-scale waste incinerators (this study was part of the CHEC ITOB consortia activities and is reported separately elsewhere, and partly in Frandsen et al. **V**). The waste fractions studied comprised PVC, shoes, shredder waste and CCA-impregnated wood, and the release of metals, S and Cl to the gas phase was quantified as a function of temperature in the interval 500 – 1000 $^{o}$C in a lab-scale fixed-bed reactor. In general, the elements Al, Ca, Cr, Cu, Fe, Mg, Si and Ti were not released, in consistency with the non-volatile nature of these elements. For the target elements Pb, Zn, K, Na, Cl, and S, the lab.-scale release was found to be both temperature dependent and to some extent fuel specific.

Chlorine release was found to be complete already at 500 $^{o}$C for PVC, whereas for the other laboratory fuels, there was a gradual increase in the Cl release from 500$^{o}$C to 1000 $^{o}$C. This is in good consistency with the full-scale observations and confirming that Cl from PVC is released as HCl(g) already at low temperatures.

K, Na, Zn and Pb were all released to a significant extent to the gas phase above 750 $^{o}$C, under the conditions prevailing in the fixed bed. The release of Pb at 750 $^{o}$C was found to correlate linearly with the S/(S+Cl) ratio in the fuels ($R^2$ = 0.92), consistent with the full-scale observations and confirming that at least at moderate temperatures (around 750 $^{o}$C) Cl and S in the fuel may be influencing the volatility of Pb.

All in all, the lab-scale release results were found to correlate quite well with the observations from the full-scale study, when taking into account the different fuel matrix (dedicated waste fractions vs. blended waste) and the generally more complex conditions prevailing during the full-scale incineration experiments. The obtained results suggested that lab-scale release experiments on dedicated waste fractions can be used to gain reliable information on the release of inorganic elements, and subsequent formation of fly ash and aerosols, during full-scale waste incineration. It may not be possible to extrapolate the data quantitatively, as the conditions during full-scale waste incineration are very complex, but the method proves a useful tool when it comes to predicting overall trends and identify possible release mechanisms attributed to specific waste fractions.

## Overall link: Aerosols – fly ash – deposits

An increased mass-load of fine particles when adding salt to the feedstock, but not when adding PVC, was suggested to reflect that the chlorine in PVC was released as HCl(g), while the chlorine in salt was particle bound. Addition of salt also changed the chemical composition and particle size distribution of the total fly ash, towards an increased concentration of Na and Cl, and a smaller particle size, indicating increased condensation of alkali-chlorides.

The study of the deposit formation, however, displayed somewhat different results. Still, in the interpretation of these results one should bear in mind that the deposits were sampled at the entrance to the convective section, at a flue gas temperature close to 600 $^{o}$C and with a surface temperature of the deposition probe of 400 $^{o}$C, whereas the aerosols were sampled downstream of the convective section, at a flue gas temperature of app. 175 $^{o}$C (see Figure 1). This gives rise for different ash transformations in the two cases.

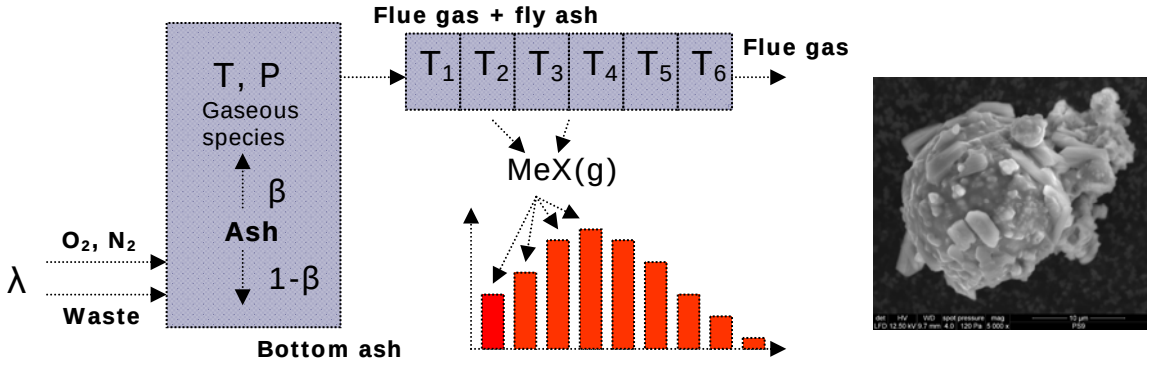


*Figure 9. Model approach – heterogeneous condensation of trace metals on a size distributed fly ash.*

It was found in the deposition study that the rate of deposit build-up ($g/m^2/h$), as well as the concentration of Cl in the deposits, was increased when firing PVC, while no significant effects on the deposit formation were observed when firing salt. The chemical analysis of the deposits from the PVC run revealed that the deposits were also relatively high in [Ca], while the alkali content was relatively low. Hence we suggest that the increased deposition flux, and high [Cl], in the deposits from the PVC run may be explained by increased condensation of $CaCl_2$ on the deposition probe in this specific run. Ca-compounds, such as $CaCO_3$, are added routinely to various PVC-products, as fillers.

## Modeling of heterogeneous condensation

A physical model for heterogeneous condensation of trace elements on a size distributed fly ash was to be developed and coupled with an existing equilibrium model. The model is summarized below, and more details are provided in Appendix **VIII**.

### Approach

A two-compartment system: (1) Release from the grate: Vaporization of elements. (2) Condensation of elements in the flue gas channel as a function of T. The idea is sketched in Figure 9. The model is one-dimensional in time and consists of (1) specifying the initial conditions in the system (2) computing the target element condensation as a function of T. Gas/solid equilibrium is calculated at each step using the commercial equilibrium model FactSage$^{TM}$ (version 5.2), and interactions between vapor phase and particle surface are calculated by fluxes, with units of moles per second per particle. A flow chart of the model is outlined in Figure 10.

### Assumptions and limitations

Heterogeneous condensation (i.e. surface condensation on existing fly ash particles) is assumed to be the only mechanism by which particulate matter becomes enriched with heavy metals (chemical reactions are neglected).

The condensation flux equation, $R_{cond}$, ($mol/m^3 \cdot s$), on uniform sized spherical particles of diameter $d_p$ (m) in the continuum (supermicrometer) regime is diffusion limited and given by equation (2).

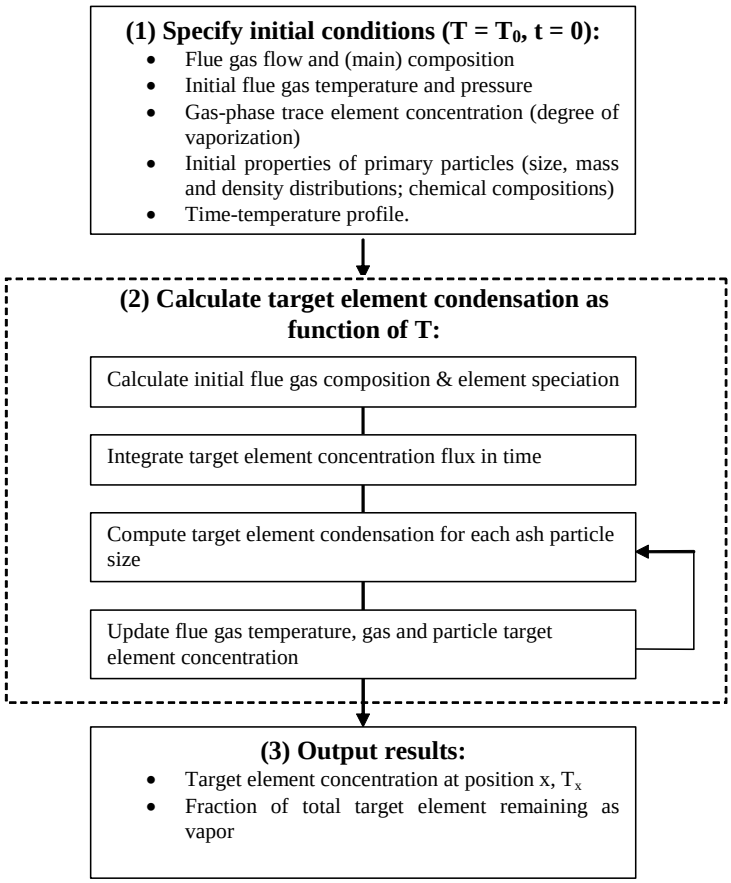


*Figure 10. Flow chart for modeling of heterogeneous condensation on a size distributed fly ash. Target element: Pb, Zn, Cu, Cd etc.*

$$R_{cond} = F_i(d_p) = \frac{2 \cdot \pi \cdot d_p \cdot D_{Xm}}{R \cdot T} \cdot P_{LOAD} \cdot (p_\infty - p_s) \cdot \left[ \frac{1 + Kn}{1 + 1.71 \cdot Kn + 1.333 \cdot (Kn)^2} \right] \quad (2)$$

where $D_{Xm}$ is the molecular diffusivity of X in a multicomponent gas, m, $p_\infty$ and $p_s$ is the bulk and surface pressure of X, $P_{LOAD}$ ($1/m^3$) is the particle loading of the gas, and $Kn = 2\lambda/d_i$ is the Knudsen number. The term in the brackets is the Fuchs-Sutugin correction for the non-continuum behavior of small particles. λ: the mean free path of the gas molecules (~0.5 μm for combustion gases). $D_{Xm}$ can be estimated for any molecular component X in m using *an empiric equation* of Fuller, Schettler and Giddings, which utilizes diffusion volumes.

To solve for a size distributed fly ash, the particle size distribution is discriminated and the flux equation is solved for each size fraction.

**Data fitting / validation of the model**

The mass fraction of a condensed species, $Wi(d_p)$ is given by the mass condensed (in time, t), on the particle of size $d_p$ divided by the particle mass.

Different condensation mechanisms will yield different dependencies of $F(d_p)$ on $d_p$, and it can be shown that for Kn<<1 (coarse fraction particles), $Wi(d_p) \sim 1/d_p^2$, while for Kn>>1 (fine fraction particles), $Wi(d_p) \sim 1/d_p$. However, several studies of coal fly ash have shown that experimental data are not always in consistence with this physical condensation theory. Often the trace elements (As, Ni, Cd etc.) better obey a $1/d_p$ dependence, even for larger particles, suggesting that surface condensation alone cannot account for the trace element distribution (chemical reaction mechanisms are also involved).

The Pb concentration in the FASAN ash as a function of particle diameter is illustrated in Figure 11 (measured and calculated values). The calculated value is a "first rough estimate" of the condensation flux, assuming an initial Pb concentration of 0.005 ppm(v) in the gas phase. At the point of sampling (T ~175 $^oC$), all Pb is assumed to be condensed (as $PbCl_2(s)$). The initial Pb concentration ($C_0$) in the coarse particles is set to 697 mg/kg (residual concentration), while $C_0$ is set to 0 in the aerosols.

It is seen that the Pb concentration better obeys a $1/d_p$ dependence as compared to a $1/d_p^2$ dependence (the same trend is found for other trace elements as Hg, Cd, Zn and Cu, results not shown). The heterogeneous condensation model seems to correctly predict the trends in the experimental data, although it is also seen that the model may tend to over-estimate the Pb concentration in the fine particles.

An over-all evaluation of the equilibrium condensation temperatures revealed that most of the trace elements (including As, Zn, Cu) have relative high condensation temperatures (> 500 – 700 $^oC$), and only Hg, Cd and Pb may be expected to be still in the gas phase at temperatures below ~400 $^oC$. This lead us to conclude that the potential for alternative/selective capture of fly ash (at higher temperatures), in order to improve the ash quality, is limited. On the other hand, the quality of the bottom ash might be improved slightly by taking out the boiler ash separately, instead of mixing it with the bottom ash (which is currently the normal procedure at many plants).

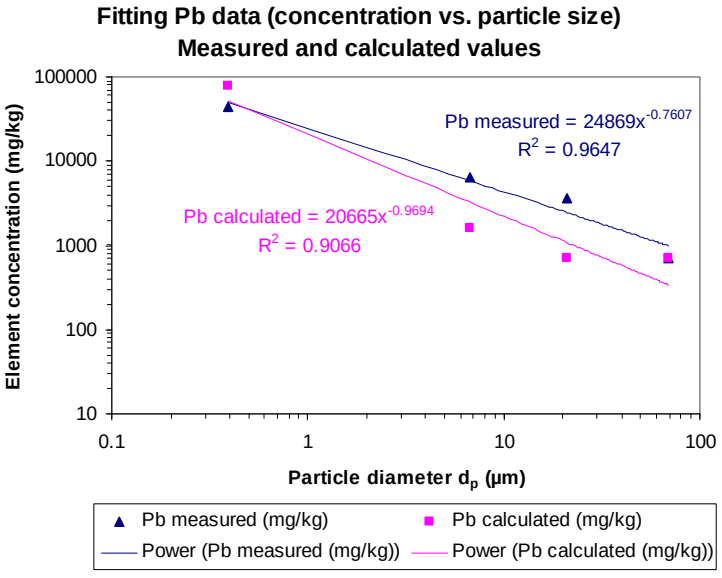


*Figure 11. Pb concentration in FASAN ash as a function of particle diameter. Measured and calculated values.*

# 4. Residue leaching

## Overview of leaching experiments

As mentioned in the Introduction, bottom ash samples from 12 different experiments were collected at FASAN; these will be referred to as "FASAN residues" (elemental composition is given in Appendix **VII**, Table VII-2). In order to evaluate leaching, the FASAN residues were subjected to CEN 12457-1 (L/S 2 L/kg) compliance leaching experiments (Appendix **VII**, Table VII-3,4,5).

Secondly, in order to provide a reference for comparison of bottom ash leaching data, a range of "averaged one-year" samples of bottom ash was collected from Vestforbrænding, Nordforbrænding, KARA, and Århus (furnace 2 and 3). Note that these materials were not subjected to CEN 12457-1 as these data were obtained from regulatory compliance testing supplied by either the incinerators or AFATEK A/S. Instead, these materials were subjected to CEN 14405 column experiments (Appendix **VII**, Table VII-8) thus providing additional information about time-dependent leaching.

Thirdly, in order to provide sort of a reference leaching data for Danish fly ash/APC residues, a range of "averaged one-year" samples of fly ash/APC residues was collected from Amagerforbrænding, Nordforbrænding, KARA, Odense, Vestforbrænding, and Århus. These materials were subjected to CEN 12457-1,4 batch tests (L/S 2 and 10 L/kg, respectively) as well as CEN 14405 column experiments (Appendix **VII**, Table VII-6,7,9).

In the following text primarily the results from the 12 experiments at FASAN are discussed. The experiments carried out using different operational parameters and different waste input compositions are in this chapter referred to as "OC" and "WI", respectively.

Comparison with regulatory compliance leaching data is provided where appropriate.

## Cl leaching

Figure 12 shows Cl contents in fresh bottom ash samples and associated leaching of $Cl^-$ . The highest $Cl^-$ leaching was observed in samples from the experiments with road salt (4720 mg $kg^{-1}$ TS) and PVC (2700 ± 320 mg $kg^{-1}$ TS). Correlation between the Cl content and $Cl^-$ leaching was not observed for the OC experiments ($r^2$ = 0.18) whereas a clear correlation was found for the WI samples ($r^2$ = 0.86). Thus, positive correlation between the Cl content in bottom ash and $Cl^-$ leaching was found. Comparing the results from the OC and WI experiments it appears that although changes in OC may affect the leaching of $Cl^-$ to some extent, the presence of Cl in the incinerated material has a more direct influence on $Cl^-$ leaching.

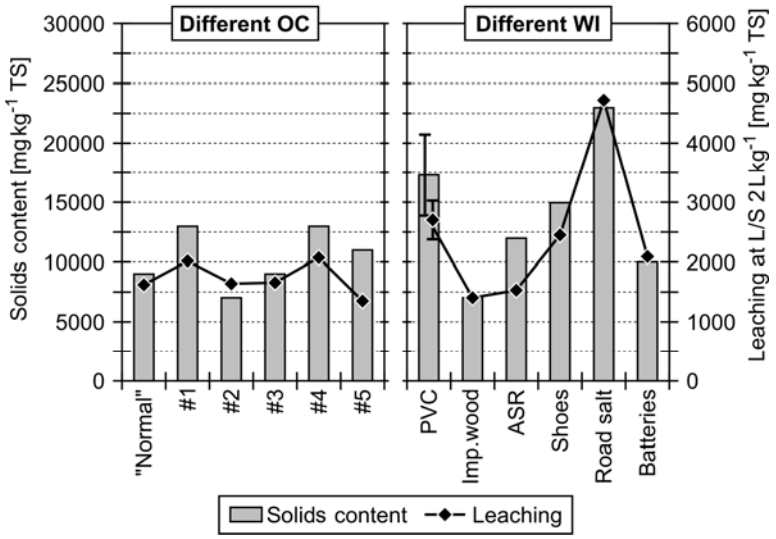


*Figure 12. Bulk contents of Cl in fresh bottom ash (primary y-scale) and $Cl^-$ leaching from fresh bottom ash (secondary y-scale) (Hyks and Astrup **IV**).*

## Evolution of pH during ageing

The leaching of metals in particular is strongly pH-dependent and may thus only be discussed when pH during the leaching experiments is considered. Table 4 shows range of pHs for fresh, naturally aged, and lab-scale aged bottom ash samples. Three months of outdoor ageing did not affect pH compared with the fresh bottom ashes while the lab-scale aged samples showed about 1-2 pH units lower values compared with the fresh bottom ashes. Although pH of the lab-scale aged samples was found semi-stable, ageing/carbonation process was likely far from complete as this would typically be characterized by pH 8.5.

*Table 4. pH of fresh, naturally aged, and lab-scale aged bottom ash (in leachates) generated during incineration of the reference waste with or without addition of specific waste fractions (Hyks and Astrup **IV**).*

| Bottom ash | **OC experiment: reference waste only** | | | | | |
|---|---|---|---|---|---|---|
| | **Normal (Ref.)** | **#1 (Min $O_2$)** | **#2 (Max $O_2$)** | **#3 (Dec.sec.)** | **#4 (Inc.sec.)** | **#5 (Undef.)** |
| Fresh | 11.35 | 11.38 | 11.34 | 11.32 | 11.03 | 11.19 |
| Naturally aged | 11.35 | 11.09 | 11.41 | 11.31 | 11.22 | - |
| Lab-scale aged | 9.44 | 9.45 | 9.24 | 9.21 | 10.03 | 9.70 |

| Bottom ash | **WI experiment: reference waste + added fraction** | | | | | |
|---|---|---|---|---|---|---|
| | **PVC** | **Imp. wood** | **Shredder waste (ASR)** | **Shoes** | **Road salt** | **Batteries** |
| Fresh | 11.69 ± 0.2 | 11.57 | 11.03 | 11.40 | 11.49 | 10.88 |
| Naturally aged | 11.29 ± 0.2 | 11.31 | 11.05 | 11.33 | 11.32 | 10.56 |
| Lab-scale aged | 9.65 ± 0.10 | 9.29 | 9.80 | 9.53 | 9.83 | 9.16 |

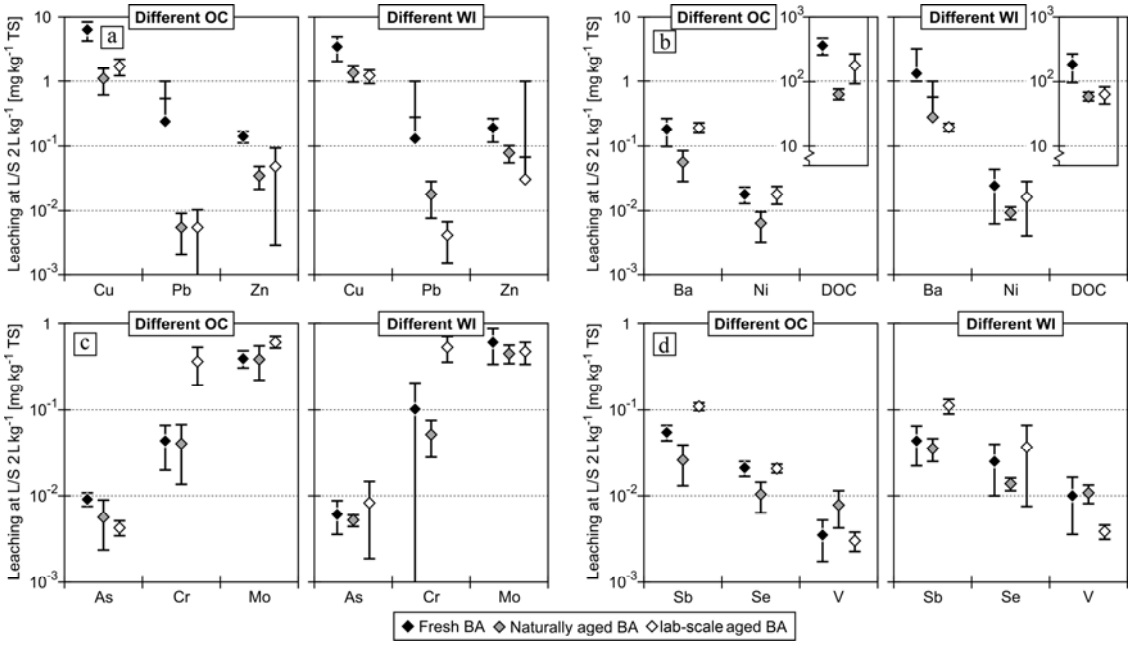


*Figure 13. Leaching from bottom ash (BA) generated during incineration of the reference waste at different OC and different WI. Leaching from fresh, naturally aged, and lab-scale aged BA samples is expressed as black, gray, and white diamonds respectively. Mean values and 90 % confidence intervals are shown; note the different scale in case of DOC (Hyks and Astrup **IV**).*

## Leaching of metals

### Fresh FASAN residues

Figure 13 shows the mean values and 90 % confidence intervals for the leaching of Cu, Pb, Zn, Ba, Ni, DOC, As, Cr, Mo, Sb, Se, and V from fresh bottom ashes generated in the OC/WI experiments. The leaching was notably similar (within a factor of 3) for all element pairs except Ba, which was likely related to different leaching of sulfate (details in Hyks and Astrup **IV**). The WI leaching data showed somewhat larger variations compared with the OC leaching data (e.g. Ni, Cr). Correlations between the bulk content and leaching were not found for any metal (including Ba). Overall, the leaching of metals appeared to be independent of the bulk contents and, in turn, changes in OC as well as WI; note similar pH of the fresh samples (Table 4).

Leaching of Be and Cd in all samples was found below 0.9 and 0.3 µg $L^{-1}$, respectively (i.e. below detection limit of used ICP-OES). These elements are therefore neither shown graphically nor discussed further.

Leaching of Co (not shown graphically) was generally found around the detection limit except the residues generated in the experiment with batteries where the leaching from fresh and also lab-scale aged samples increased to about 30 µg $kg^{-1}$ TS. Co is currently not regulated (in case of landfilling in EU) and so far Co leaching has received little attention in particular with respect to leaching control mechanisms. The results of the CEN 12457-1 leaching test did not allow concluding on any specific leaching mechanism or calculating correlations between the bulk contents and leaching. Nevertheless, caution is advised in relation to incineration of batteries.

**Aged FASAN residues**

Figure 13 also shows the mean values and 90 % confidence intervals for leaching from naturally aged and lab-scale aged samples. For many elements (e.g. Pb, Zn, Cr), ageing had greater impact on leaching than the induced changes to OC/WI. At full-scale, ageing of bottom ash is generally accepted to decrease leaching of most metals and is a widely used method to improve bottom ash quality. This was, however, only the case for Pb, Zn, and Cu which were likely controlled by sorption, precipitation and complexation with DOC (Hyks and Astrup **IV**).

Leaching of Ba from the naturally aged OC samples was found lower than from the lab-scale aged OC samples whereas the situation was opposite for the WI samples. Nevertheless, Ba leaching from both lab-scale aged residues was found at the same level: ± 0.2 mg $kg^{-1}$ TS. Barite ($BaSO_4$) and to some extent also $Ba_{0.5}Ca_{0.5}SO_4$ solid solution ($K$ = $10^{-7.41}$) were found plausible to explain Ba concentrations.

Ni showed similar leaching patterns for both OC and WI samples with leaching around 7-20 µg $kg^{-1}$ TS. This could be caused by a combination of $Ni(OH)_2$(s) precipitation and surface complexation to Fe/Al (hydr)oxides. According to our modeling the solution concentrations of Ni fell between the solubility of $Ni(OH)_2$(s) and bunsenite (NiO).

The leaching of some oxyanions (Cr, Sb) increased with carbonation possibly due to dissolution of their bearing phases (e.g. Cr-ettringite and calcium antimonite) at pH < 10.5 (Fig. 13c and 13d). Thus, although ageing can generally decrease leaching of cationic metals the same process may also result in significant increase in the leaching of some oxyanions compared with the fresh residues: Cr and Sb seem to be of major concern due to their toxicity and concentration levels. In real-life system the one order of magnitude increase in the leaching of Cr may further increase towards higher L/S ratios (or with continued carbonation) as Cr leaching from the carbonated bottom ash was reported to reach concentrations up to 2 mg $kg^{-1}$ TS at pH 8.5. In addition, oxidation of Al(0) during carbonation may lower the "reduction capacity" of the ashes thereby allowing Cr to get oxidized and leach from the aged ashes.

Other oxyanions (As, Mo) showed relatively stable leaching from all three material types. For As, fairly flat sorption edges on Fe-oxides were reported at pH > 9 and phosphate levels similar to our experiments. For Mo, virtually the same leaching from all three material types (Figure 13c) could well be caused by a single controlling process. Since the leachates were found undersaturated with respect to $CaMoO_4$ and low affinity of $MoO_4^{2-}$ for substituting $SO_4^{2-}$ in ettringite is low, weak surface complexation at pH > 9 seemed plausible.

## Comparison with other leaching data

**Leaching data from regulatory compliance testing**

In Figure 14 leaching data for the FASAN residues ($F_{OC}$, $F_{WI}$) were compared with leaching from bottom ash generated during 2006 – 2008 at six Danish MSW incinerators which typically incinerate mixes of MSW from households, recycling stations, industry, etc. with varying ratios between household waste and industry waste. Bottom ash from I/S FASAN (referred to as "F" in Figure 14) used in this comparison was not collected as part of the OC/WI experiments at I/S FASAN but collected as part of the required compliance testing. All bottom ashes were aged outside 1-4 months prior to the CEN 12457-1 leaching experiments.

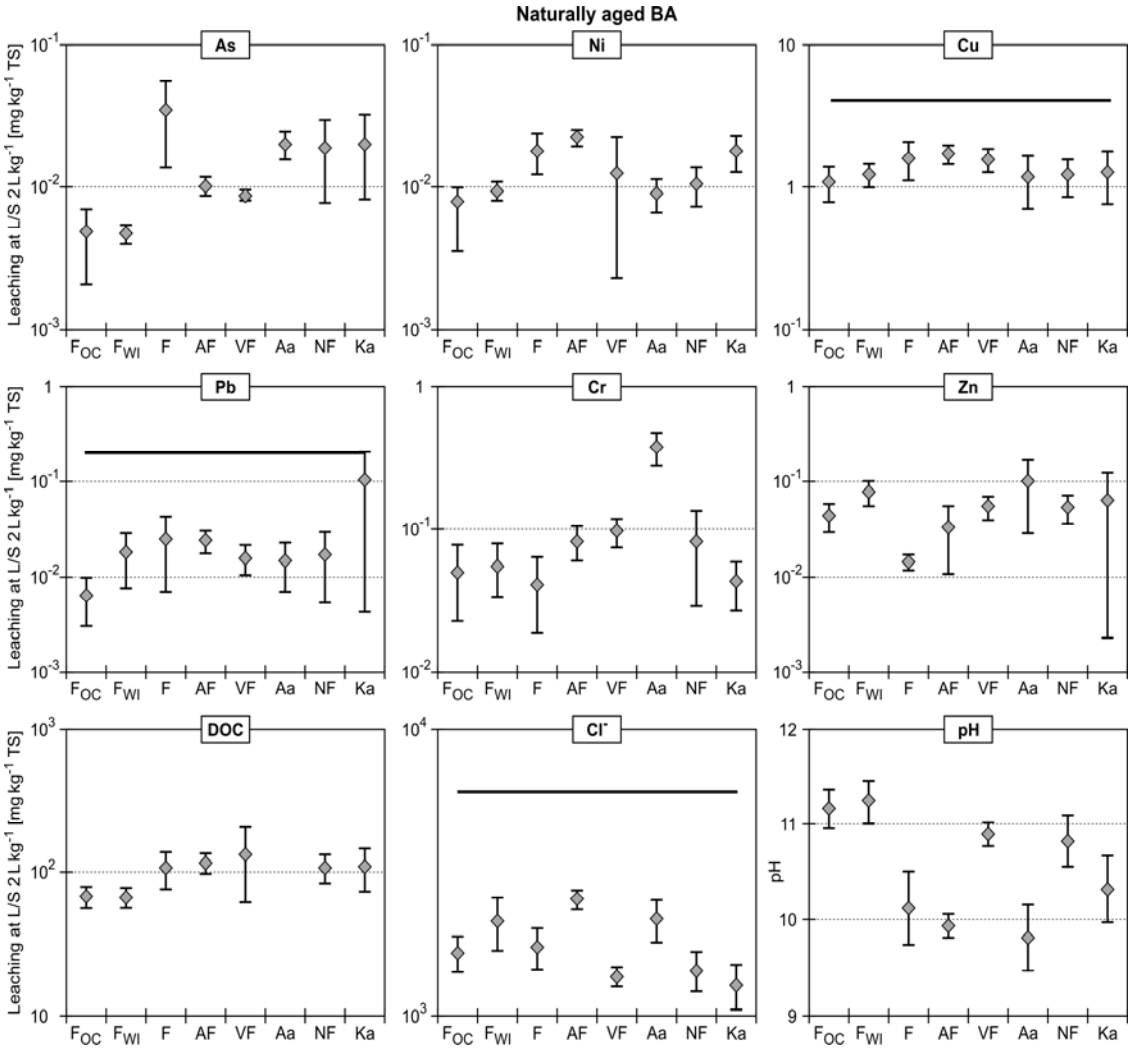


*Figure 14. Mean values and 90 % confidence intervals for leaching from bottom ash (BA) generated at different Danish MSW incinerators in a period from January 2006 to September 2008. Abbreviations and sample populations: F (I/S FASAN, n = 11), AF (I/S Amagerforbrænding, n = 37), VF (I/S Vestforbrænding, n = 39), Aa (I/S Århus, n = 13), NF (I/S Nordforbrænding, n = 13), and Ka (I/S KARA, n = 21). Leaching data generated during the experimental campaign at I/S FASAN are referred to as $F_{OC}$ and $F_{WI}$. Solid black lines in case of Cu, Pb, and $Cl^-$ represent Danish material utilization limits for Category 3 (Hyks and Astrup **IV**).*

The leaching of some elements (e.g. Cu, DOC, $Cl^-$) was similar for all MSW incinerators whereas other elements (e.g. Cr) showed larger fluctuations between individual plants. However, it should be emphasized that given the differences in incinerator technology, operation, MSW composition, ash pH and sampling (performed by the incinerator operators), the leaching was in fact similar: typically with variations within one order of magnitude between the incinerators. The Danish regulatory limits for material utilization (Category 3) were met in all cases (these limits are indicated by solid lines in Figure 14 where appropriate). In this perspective, incineration of the previously mentioned amounts of additional waste materials (PVC, impregnated wood, ASR, shoes, batteries) during the OC/WI experiments at I/S FASAN did *not* appear to affect the leaching properties of the bottom ash significantly, at least when compared with typical naturally aged ashes from Danish MWS incinerators.

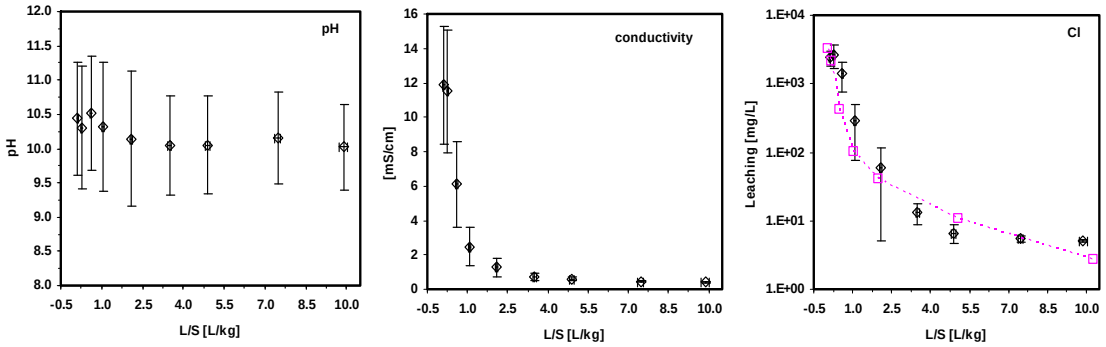


*Figure 15. pH, conductivity and leaching of Cl obtained during the CEN 14405 column experiments with "averaged one-year" samples of bottom ash; mean values and STD are shown. Data indicated by a dashed line represents leaching from fresh bottom ash subjected to CEN 14405).*

## Column leaching data

### Bottom ash samples

Results of the CEN 14405 column experiments carried out with five "averaged one-year" samples of bottom ash collected at Vestforbrænding, Nordforbrænding, KARA, and Århus (oven 2 and oven 3) are shown in Figure 15 and 16 (details in Appendix **VII**, Table VII-8). Note that leaching data determined in dynamic experiments (i.e. column test) cannot be directly compared with results of the batch experiments since different mechanisms are involved. Nevertheless, the columns still provide a valuable piece of information about time-dependent leaching and possible long-term trends.

It could be seen in Figure 15 that mean pH value did not changed significantly over the course of the experiments while the variations likely reflected the fact that different "aged" residues were tested (compare with variations in pH values in Figure 14). Cl as well as conductivity displayed their typical behavior: both decreased rapidly before L/S 3 L/kg was reached as a consequence of initial washout of the readily soluble compounds (e.g., NaCl, KCl, $CaCl_2$).

Leaching of metals (Figure 16, next page) from the five materials was relatively similar, although variations were found somewhat larger (up to three orders of magnitude in total) than in case of the batch experiments shown in Figure 14. Higher variations between columns could be caused, among other things, by different magnitude of non-equilibrium conditions during the dynamic leaching experiments. Still, it appears from the data shown in Figure 16 that the leaching of metals was controlled by similar mechanisms: mainly solubility control (e.g. Pb, Ba, Zn, Sb) and depletion/complexation (e.g. Cu, Mo). The differences in leaching between aged and fresh residues (represented by dashed lines) reflected the same patterns outlined in Figure 13. For instance, the leaching of Pb from the fresh residues was higher than the leaching from the "averaged one-year" samples, which were aged to some extent.

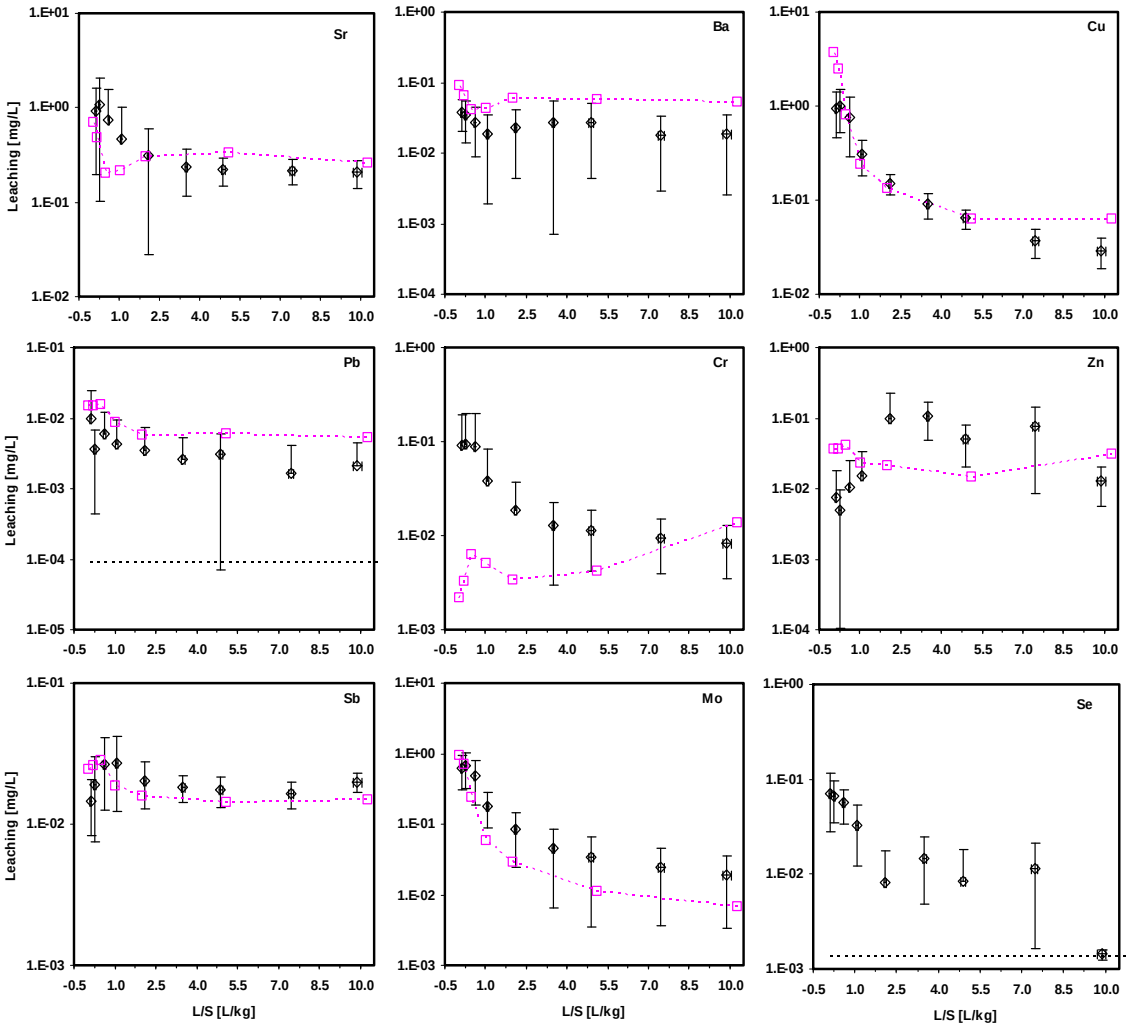


*Figure 16. Leaching of metals (refined) obtained during the CEN 14405 column experiments with "averaged one-year" samples of bottom ash; mean values and STD are shown. Data indicated by a dashed line represent leaching from fresh bottom ash subjected to CEN 14405. Horizontal line in case of Pb and Se symbolizes detection limit.*

## Fly ash/APC residues samples

Dynamic leaching was also quantified in case of fly ash/APC residues. In contrast with the above discussed bottom ash samples, the leaching from fly ash/APC residues showed significantly greater variations for some pollutants (e.g. Cr, Sb, Pb); for details see Appendix **VII**, Table VII-9.

In Figure 17 an example of observed leaching from "averaged one-year" samples of fly ash/APC residues collected at Århus (Aa), Vestforbrænding (VF), Amagerforbrænding (AF), Odense (Od), Nordforbrænding (NF) and KARA (Ka) is given together with leaching data for fly ash/APC residues collected by simple grab-sampling at AF and VF (data from another study). It could be seen that e.g. the leaching of Ba and Mo from the "averaged one-year" samples (indicated by data points) is to some extent comparable with leaching from fly ash/APC residues collected by simple grab-sampling (indicated by lines). At the same time, however, the leaching of Cu and Pb in particular shows variations of up to five orders of magnitude during the initial leaching (below L/S 1 L/kg).

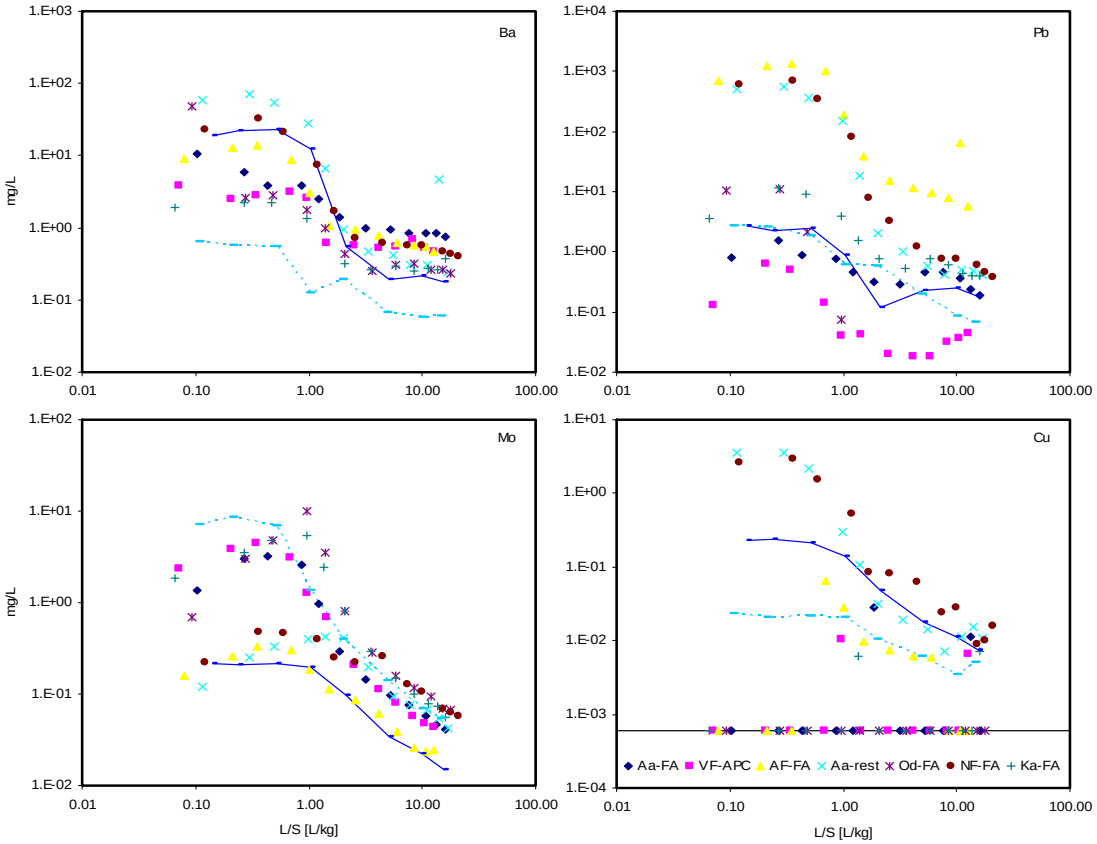


*Figure 17: Leaching of Ba, Pb, Mo, and Cu from "averaged one-year" samples of fly ash/APC residues compared with leaching of two residues sampled by grab-sampling (indicated by lines). Horizontal line in case of Cu symbolizes detection limit.*

This reflected the nature of fly ash/APC residues which composition is extremely dependent on the composition of the waste input (Astrup et al. **I**; Pedersen et al. **II**) and performance of the flue gas control system. In addition, great bulks of the total contaminant contents may be present as part of highly soluble compounds (generally metal chlorides). Consequently, in contrast with bottom ash, it may not be possible to define "typical" range for leaching from Danish fly ash/APC residues and residues from different plants should always be tested individually.

# 5. Project conclusions

The overall objective of the project was to improve the understanding of the formation and characteristics of residues from waste incineration. This was done focusing on the importance of the waste input and the operational conditions of the furnace. Data and results obtained from the project have been discussed in this report according to the following three overall parts: i) mass flows and element distribution, ii) flue gas/particle partitioning and corrosion/deposition aspects, and iii) residue leaching. This has been done with the intent of structuring the discussion while tacitly acknowledging that these aspects are interrelated and cannot be separated.

Overall, it was found that the waste input composition had significant impact of the characteristics of the generated residues. A similar correlation between operational conditions and residue characteristics could not be observed. Consequently, the project recommend that optimization of residue quality should focus on controlling the waste input composition. The project results showed that including specific waste materials (and thereby also excluding the same materials) may have significant effects on the residue composition, residue leaching, aerosol and deposit formation It is specifically recommended to minimize Cl in the input waste. Based on the project results, it was found that a significant potential for optimization of waste incineration exist.

In the following, more detailed conclusions of the various aspects are provided.

## Mass flows and element distribution

Based on mass balance calculations, it was found that experiments with different waste materials significantly altered the waste input composition of both heavy metals, organic and inorganic Cl. Salt contributed with considerable quantities of Na and Cl, Shoes were adding Cd and Cl to the waste mix, Shredder Waste contributed with a range of metals. Batteries contributed with high amounts of Cd, Co, Hg, S and Sr relative to the base-load waste, PVC Waste contributed with Cd and Cl, while Impregnated Wood added As, K, Pb, S and Si.

The consequences for the solid residues and air emissions were evaluated by taking into account both the concentration levels in the actual ashes, as well as the amount of an element routed to the individual ashes. While increased concentrations of e.g. As, Cu, and Mo in the solid residues coincided with waste fractions having high contents of the same element, increased concentrations of Cr, Ni, and Pb could not be fully explained with higher input levels. This indicated that the waste mix was important but also that other constituents and mechanisms, such as mobilization of Pb by Cl, controlled ash concentrations: organic-bound Cl (as in PVC and shoes) favored higher concentrations in the fly ashes while inorganic Cl (salt) shifted Pb towards the bottom ashes.

It was not possible to relate the composition of the solid residues to changes in plant operational parameters (the variations induced by changes in operational conditions could not be distinguished from the natural fluctuations). This does not mean, however, that such correlations may not exist only that in view of the complexity and dynamic properties of a full-scale system, such mechanisms could not be observed. The operational changes induced in these experiments were made as large as possible considering the furnace, still the resulting effects on residue

characteristics were less pronounced than the effects from changes in waste input. Based on this it was concluded that priority should be placed on optimization with respect to the waste input.

## Flue gas/particle partitioning and corrosion/deposition aspects

Cl and S played an important role for the behavior of Pb, and probably also other metals. When incinerating Cl-rich waste fractions, the partitioning of Pb appeared to shift towards increased vaporization, whereas the opposite was observed for S-rich waste fractions. This was explained by formation of volatile Pb-chlorides at high Cl concentrations, and stable Pb-sulphates at high S concentrations. Organic-bound Cl (as in PVC and shoes) was preferably released (as HCl(g)) to the gas phase, while inorganic Cl (salt) was mainly recovered in the bottom ash and fly ash fractions (indicating alkali-chloride binding).

In addition to affecting overall distribution of Pb between the residues, Cl in the waste appeared to: i) enhance the vaporization of heavy metals (primarily Pb, but probably also Zn), ii) cause increased mass-load of aerosols if present as alkali-chloride in the waste, and iii) cause increased deposition fluxes and higher concentrations of Cl in the deposits. It was suggested to minimize the Cl/S ratio in the input waste as this may reduce corrosion in the boiler sections by shifting the equilibrium from the highly corrosive species $PbCl_2$ and $ZnCl_2$ to less corrosive species such as $PbSO_4$ and $ZnSO_4$. Deposit formation was the only aspect which appeared significantly correlated with the operational conditions. "Minimum $O_2$" and “Undefined Conditions” gave significantly lower Cl in the deposits while "Increased Secondary Air" showed a significantly higher deposition flux.

High input concentrations of heavy metals also appeared to be problematic: e.g. in case of shredder waste and CCA impregnated wood, high loads of Zn and/or Pb resulted in increased concentrations of these two elements in both fly ash and aerosols (and deposits), although the overall partitioning was not altered. Consequently enhanced deposition and corrosion problems may be induced in the boiler.

The potential for alternative/selective capture of fly ashes, in order to improve the ash quality, appeared to be limited as most heavy metals condense at relatively high temperatures. Control of the input waste composition was concluded more relevant for optimization.

## Residue leaching

No clear correlation between the bulk contents of the bottom ashes and the leaching was observed for the changes induced in waste input and operational conditions, except in the case of Cl ($r^2 = 0.86$). This indicated that Cl leaching from bottom ashes may be reduced by limiting Cl in the waste received at the incinerator, potentially by improved source separation. Leaching experiments on fly ash samples collected during the experiment could not be carried out as only a few grams could be collected due to practical reasons. It was not possible to observe correlations between changes in operational conditions and leaching.

Differences in metal leaching between samples obtained in this study could primarily be associated with differences in ageing: leaching of cationic metals from aged bottom ashes was generally lower than from fresh ashes whereas ageing had

negative effects on leaching of Sb and Cr. The observed variations in leaching data from these experiments generally appeared within the ranges in leaching data observed for typical Danish MSW incineration bottom ash. Although similar mechanisms control the leaching in different bottom ashes, variations in element leaching of about one order of magnitude appear typical for Danish bottom ashes.

# 6. Suggestions for further research

During the course of the project, two workshops were carried out with participation from major Danish stakeholders. The latter of these workshops was concluded with a discussion of the outcome of the project. A general appreciation with the work performed in the project was expressed from the participants and it was found that the project results would likely form a solid basis for future research and development within the field. Based on discussions in the workshops, among the project partners, feedback on international conferences and other stakeholders a range of important aspects relevant for further research has been identified:

- The interdisciplinary collaboration within the project group has been very advantageous in our opinion. In order to better benefit from the data generated in this project, further develop the understanding of chemical interactions between the different elements, and make the experimental full-scale data from the project more evident, we hope to continue with the PSO-5784 group of participant in future follow-up projects.
- The experiences related to the full-scale experiments carried out in this project clearly showed that the approach of adding specific waste materials to a base-load waste were extremely useful for assessing to which extent these waste materials affected the emissions from the plant. The project also showed that it was possible to complete a range of individual experiments within a rather limited time schedule. Further full-scale experiments with other waste mixes are suggested to supplement the results from this project.
- Although this project included an unprecedented range of measurements on a full-scale plant while at the same time varying key parameters, the dynamics and complexities of the involved full-scale processes is a limiting factor for investigation of the more detailed processes responsible for formation of the residues. More detailed data supplementing the results gained in this project is therefore suggested to be carried out based on lab-scale experiments.
- Lab-scale experiments focused on element release and ash formation of specific waste materials and mixtures of waste materials are suggested to be carried out under controlled conditions. These experiments should be combined with investigation of the leaching properties of the treated waste materials, in order to better understand the relation between combustion temperature, waste composition, combustion atmosphere, and the leaching from the ashes generated.
- Lab-scale experiments are also suggested to improve the understanding of relations between the operational conditions and deposit formation as this project indicated a link in this respect.
- The importance of Cl and S is suggested to be further studied, e.g. by further development of full-scale measurements of the release profile just above the grate as done in PSO-6368.

# Appendix I

Astrup, T., Riber, C. & Pedersen, A.J. (2009): MSW Incinerator Emissions and Residues: Influence of Waste Input and Operational Conditions

# Appendix II

Pedersen, A.J., Frandsen, F.J., Riber, C., Astrup, T., Thomsen, N.S., Lundtorp, K. & Mortensen, L.F. (2009): A Full-Scale Study on the Partitioning of Trace Elements in Municipal Solid Waste Incineration – Effects of Firing Different Waste Types

# Appendix III

Zeuthen, J.H., Pedersen, A.J., Hansen, J., Frandsen, F., Livbjerg, H., Riber, C. & Astrup, T. (2007): Combustion aerosols from municipal waste incineration - effect of fuel feedstock and plant operation

# Appendix IV

Hyks, J. & Astrup, T. (2009): Influence of operational conditions, waste input and ageing on leaching of contaminants from waste incineration bottom ashes

# Appendix V

Frandsen, F.J.; Pedersen A.J.; Hansen, J.; Madsen, O.H.; Lundtorp, K.; Mortensen, L. (2008): Deposit Formation in the FASAN WtE Boiler as a Function of Feedstock Composition and Boiler Operation

# Appendix VI

Operational conditions and flue gas data for the FASAN experiments

Log data and measured flue gas composition from FASAN experiments (average values)

| | | OC experiments | | | | | WI experiments: Reference waste + added fraction | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Units** | **Reference** | **Dec. Sec.** | **Undef. Cond.** | **Min O2** | **Max O2** | **Incr. Sec.** | **Salt** | **Batteries** | **Shredder waste** | **Imp. wood** | **PVC** | **Shoes** |
| Primary air flow | $m^3/h$ | 20385 | 25843 | 24606 | 22820 | 26225 | 17677 | 23412 | 25846 | 23026 | 21146 | 20683 | 20982 |
| Furnace top nozzles (sec. 1) | $m^3/h$ | 3682 | 2713 | 2781 | 2503 | 3146 | 5476 | 4243 | 4249 | 3029 | 2413 | 3261 | 3420 |
| OFA 1 (sec. 2) | $m^3/h$ | 5231 | 4084 | 3640 | 3086 | 6428 | 4993 | 4265 | 3511 | 5722 | 5754 | 5490 | 4825 |
| OFA 2 | $m^3/h$ | 1983 | 508 | 1500 | 500 | 4762 | 1709 | 1623 | 1508 | 1731 | 1834 | 2450 | 1585 |
| Secondary air flow | $m^3/h$ | 10896 | 7305 | 7922 | 6089 | 14335 | 12177 | 10130 | 9268 | 10481 | 10001 | 11201 | 9830 |
| Total air flow | $m^3/h$ | 31282 | 33147 | 32528 | 28909 | 40560 | 29854 | 33542 | 35113 | 33507 | 31147 | 31884 | 30812 |
| $O_2$ wet | vol. % | 7 | 8 | 8 | 7 | 9 | 7 | 8 | 8 | 8 | 8 | 8 | 8 |
| Humidity (%) | % | 15 | 15 | 15 | 17 | 14 | 15 | 15 | 14 | 15 | 14 | 12 | 14 |
| Flue gas flow 1 | $m^3/h$ | 78607 | 77862 | 75632 | 72461 | 95127 | 77120 | 80161 | 83433 | 78561 | 81049 | 79693 | 77801 |
| Flue gas flow 2 (actual) | $Am^3/h$ | 92351 | 92117 | 90331 | 86192 | 116361 | 91951 | 94659 | 98618 | 92578 | 95803 | 92389 | 92416 |
| T1, lower IR | $^o$ C | 1037 | 1010 | 985 | 1018 | 991 | 1011 | 1014 | 1017 | 1028 | 1018 | 1010 | 1011 |
| T2, furnace top | $^o$ C | 865 | 912 | 928 | 912 | 890 | 1179 | 920 | 963 | 919 | 1024 | 1112 | 1124 |
| T3, EBK | $^o$ C | 976 | 953 | 934 | 973 | 924 | 961 | 946 | 949 | 965 | 970 | 954 | 958 |
| T4, EBK burner | $^o$ C | 895 | 832 | 824 | 845 | 851 | 910 | 895 | 874 | 924 | 872 | 895 | 884 |
| T4, flue gas duct | $^o$ C | 175 | 175 | 173 | 176 | 184 | 175 | 175 | 176 | 175 | 176 | 175 | 177 |
| HCl before NID | $mg/m^3$ | 322 | 263 | 342 | 290 | 344 | 598 | 335 | 317 | 331 | 358 | 749 | 519 |
| Measured flue gas composition (entrance to superheater section, T(gas) ~600 C): | | | | | | | | | | | | | |
| $O_2$ | vol. % | 7.81 | 8.35 | 8.78 | 7.69 | 10.16 | 7.61 | 7.99 | 8.7 | 7.59 | 8.31 | 8.29 | 7.67 |
| $CO_2$ | vol. % | 10.9 | 10.5 | 10 | 11.1 | 8.9 | 11 | 10.9 | 10.1 | 11.1 | 10.7 | 10.4 | 10.4 |
| $SO_2$ | ppmv (dry) | 43.4 | 32.5 | 47.7 | 29.5 | 21.9 | 53.2 | 43.4 | 66.3 | 56.5 | 92.9 | 42.3 | 23.6 |
| CO | ppmv (dry) | 2.1 | 2.5 | 0.4 | 9.6 | 1.1 | 2.9 | 1.4 | 2.9 | 1.5 | 0.3 | 4.7 | 2.9 |
| NO | ppmv (dry) | 100.1 | 89.3 | 90.8 | 80.1 | 103.6 | 89.7 | 87.3 | 84.4 | 102 | 111.4 | 100.5 | 68.6 |
| Total dust load | $g/m^3$ | 2.3 | 2.6 | 1.9 | 2.2 | 2.2 | | 2.2 | 2.8 | 1.9 | 2.1 | 2.3 | 1.8 |

# Appendix VII

Reside characteristics: solid composition and leaching

**Table VII-1.** Solid contents of the FASAN residues (fly ashes) and one-year average fly ash/APC samples from Århus.

| | | OC experiments: Reference waste only | | | | | | WI experiments: Reference waste + added fraction | | | | | | One-year Århus | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | **Reference** | **Undef. Cond.** | **Min $O_2$** | **Max $O_2$** | **Dec. Sec.** | **Inc. Sec.[a]** | **Salt** | **Batteries** | **Shredder Waste** | **Imp. Wood** | **PVC** | **Shoes** | **FA** | **APC** |
| As | mg/kg TS | 102 | 191.0 | 67.8 | 160.8 | 88.7 | | 102 | 111 | 109.4 | 2260 | 187 | 211.6 | 333 | 210 |
| Ba | mg/kg TS | 568 | 571.0 | 811.2 | 954.1 | 613.9 | | 218 | 594 | 1502.8 | 651 | 895 | 585.7 | 1600 | 446 |
| Be | mg/kg TS | <0,6 | 0.6 | <0,6 | 0.8 | <0,6 | | <0,6 | 0.631 | <0,6 | <0,6 | 0.637 | <0,6 | 0,695 | <0,6 |
| Cd | mg/kg TS | 203 | 408.0 | 137.7 | 205.0 | 159.0 | | 189 | 428 | 387.0 | 192 | 595 | 578.1 | 186 | 107 |
| Co | mg/kg TS | 15 | 21.3 | 14.9 | 23.3 | 15.9 | | 3.98 | 69.9 | 17.8 | 16.6 | 15.7 | 14.4 | 28,9 | 7,98 |
| Cr | mg/kg TS | 476 | 557.0 | 411.2 | 951.2 | 510.9 | | 185 | 581 | 379.9 | 914 | 687 | 775.0 | 579 | 159 |
| Cu | mg/kg TS | 1260 | 2530.0 | 1562.9 | 976.0 | 1308.9 | | 1950 | 909 | 3348.5 | 2340 | 2730 | 1930.1 | 1210 | 532 |
| Hg | mg/kg TS | 2.32 | 17.1 | 8.9 | 4.2 | 4.2 | | 8.23 | 53.9 | 5.8 | 10.5 | 8.37 | 7.4 | 20,1 | 14,3 |
| Mo | mg/kg TS | 36.4 | 34.1 | 29.7 | 34.1 | 32.2 | | 26.4 | 35.6 | 46.8 | 29.9 | 32.5 | 33.6 | 21,6 | 8,47 |
| Ni | mg/kg TS | 104 | 99.9 | 120.9 | 122.7 | 93.3 | | 49.4 | 144 | 109.1 | 95.8 | 93.9 | 148.9 | 89,3 | 32,4 |
| Pb | mg/kg TS | 3680 | 5500.0 | 5193.2 | 3172.9 | 3900.8 | | 7360 | 2980 | 7405.7 | 6080 | 16900 | 12028.1 | 5600 | 2270 |
| S | mg/kg TS | 37500 | 52100.0 | 39656.0 | 36655.7 | 37873.0 | | 55500 | 47800 | 44163.0 | 63500 | 38800 | 45217.8 | 53400 | 36700 |
| Sb | mg/kg TS | 726 | 749.0 | 736.2 | 380.7 | 620.2 | | 549 | 559 | 1362.8 | 855 | 647 | 929.9 | 967 | 560 |
| Sn | mg/kg TS | 356 | 410.0 | 197.6 | 91.2 | 235.4 | | 573 | 203 | 791.7 | 419 | 503 | 898.5 | 400 | 120 |
| Sr | mg/kg TS | 468 | 405.0 | 429.4 | 549.4 | 452.7 | | 71.1 | 441 | 316.2 | 426 | 437 | 295.2 | 402 | 262 |
| V | mg/kg TS | 17.4 | 23.6 | 43.5 | 28.8 | 21.2 | | 3.89 | 23.8 | 22.9 | 26.2 | 38.6 | 35.6 | 57,4 | 14,9 |
| Zn | mg/kg TS | 24000 | 33400.0 | 27169.1 | 13954.4 | 21034.7 | | 30000 | 24700 | 86405.9 | 36700 | 29700 | 37944.1 | 24500 | 12200 |
| $SiO_2$ | % | 12.1 | 10.5 | 11.9 | 16.2 | 12.4 | | 2.38 | 13.6 | 10.6 | 11.3 | 14.4 | 9.3 | 24,3 | 5,28 |
| $Al2O_3$ | % | 6.67 | 6.0 | 6.4 | 10.5 | 6.8 | | 0.708 | 8.5 | 5.1 | 6.17 | 8.21 | 6.2 | 7,96 | 2,22 |
| CaO | % | 22.4 | 18.3 | 20.8 | 28.0 | 23.1 | | 2.36 | 22.3 | 14.0 | 20.2 | 20.2 | 14.2 | 21,6 | 41,5 |
| $Fe2O_3$ | % | 1.15 | 1.1 | 1.6 | 1.4 | 1.2 | | 0.259 | 1.26 | 3.5 | 1.11 | 1.71 | 1.0 | 1,93 | 0,64 |
| $K_2O$ | % | 9.13 | 9.5 | 8.5 | 5.5 | 8.5 | | 15.5 | 7.54 | 8.0 | 8.87 | 7.26 | 11.0 | 5,37 | 2,56 |
| MgO | % | 2.23 | 2.1 | 2.4 | 3.1 | 2.7 | | 0.285 | 2.41 | 1.8 | 1.98 | 2.62 | 1.8 | 2,22 | 1,24 |
| MnO | % | 0.0887 | 0.1 | 0.1 | 0.1 | 0.1 | | 0.0177 | 0.221 | 0.1 | 0.105 | 0.128 | 0.1 | 0,109 | 0,0374 |
| $Na_2O$ | % | 9.13 | 10.1 | 8.8 | 6.1 | 8.6 | | 24.9 | 8.76 | 8.8 | 9.14 | 8.83 | 12.6 | 5,51 | 2,87 |
| $P_2O_5$ | % | 1.96 | 1.9 | 2.1 | 2.3 | 2.0 | | 0.464 | 1.96 | 1.3 | 1.84 | 1.86 | 1.3 | 1,41 | 0,45 |
| $TiO_2$ | % | 1.15 | 1.3 | 1.1 | 1.8 | 1.3 | | 0.146 | 1.55 | 1.0 | 1.11 | 1.62 | 0.8 | 1,91 | 0,194 |
| Cl | % TS | 19 | 22.0 | 20.8 | 11.9 | 18.6 | | 39.1 | 17.3 | 22.7 | 18.4 | 24.4 | 26.3 | 6,8 | 13,1 |
| F | % TS | 0.21 | 0.2 | 0.5 | 12.8 | 0.2 | | 0.1 | 0.23 | 0.5 | 0.27 | 0.24 | 0.2 | 0,23 | 0,14 |
| LOI | % TS | 21.2 | 21.1 | 22.1 | 13.9 | 20.2 | | 45.5 | 13.4 | 29.7 | 18.3 | 20.8 | 21.8 | 8,9 | 22,1 |
| TS | % | 97 | 96.6 | 94.5 | 97.8 | 96.2 | | 99.1 | 97.2 | 97.1 | 96.8 | 94.5 | 95.5 | 99,1 | 95,1 |

[a] No fly ash sample available from this experiment

**Table VII-2.** Solid contents of the FASAN residues (bottom ashes).

| | | OC experiment: reference waste only | | | | | | WI experiment: reference waste + added fraction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | **Reference** | **Min $O_2$** | **Max $O_2$** | **Dec..sec.** | **Inc.sec.** | **Undefined** | **PVC [a]** | **Imp. wood** | **Shredder** | **Shoes** | **Salt** | **Batteries** |
| As | mg/kg TS | 26.7 | 28.8 | 32.0 | 22.7 | 19.4 | 20.7 | 28.77 ± 5.92 | 57.3 | 27.5 | 23.2 | 34.8 | 23.3 |
| Ba | mg/kg TS | 917 | 3170 | 1040 | 1350 | 1080 | 1690 | 1747 ± 298.6 | 1380 | 4830 | 1230 | 905 | 1440 |
| Be | mg/kg TS | 0.79 | 0.621 | 0.902 | 0.738 | 0.975 | 0.838 | 0.91 ± 0. 074 | 0.804 | 0.631 | 0.861 | 0.876 | 0.631 |
| Cd | mg/kg TS | 2.68 | 1.67 | 4.02 | 2.52 | 4.41 | 2.29 | 3.12 ± 1.713 | 1.02 | 1.44 | 2.55 | 3.59 | 7.53 |
| Co | mg/kg TS | 19.8 | 38.9 | 47.0 | 41.0 | 79.4 | 30.1 | 33.06 ± 11.16 | 27.3 | 49.4 | 54.7 | 32.9 | 222 |
| Cr | mg/kg TS | 316 | 552 | 727 | 590 | 402 | 387 | 469.5 ± 60.53 | 527 | 487 | 617 | 386 | 378 |
| Cu | mg/kg TS | 18700 | 10600 | 4240 | 1840 | 5620 | 3930 | 3473 ± 3448 | 5500 | 21400 | 2200 | 1950 | 3090 |
| Hg | mg/kg TS | 0.021 | 0.0185 | 0.026 | 0.024 | 0.018 | 0.022 | 0.0402 ± 0.029 | 0.03 | 0.029 | 0.017 | 0.024 | 0.0295 |
| Mo | mg/kg TS | 6.98 | 29 | 7.06 | 15.0 | 14.9 | 11.9 | 10.58 ± 1.294 | *6* | 37 | 12.3 | 10.3 | 13.5 |
| Ni | mg/kg TS | 179 | 290 | 305 | 170 | 731 | 304 | 213.7 ± 77.1 | 515 | 913 | 170 | 200 | 331 |
| Pb | mg/kg TS | 697 | 1080 | 1740 | 9150 | 1770 | 2960 | 1899.8 ± 1273 | 4470 | 2230 | 704 | 1090 | 2640 |
| S | mg/kg TS | 2190 | 2640 | 4930 | 4360 | 4500 | 4900 | 3016 ± 495 | 9260 | 3860 | 5310 | 2970 | 10100 |
| Sb | mg/kg TS | 54 | 126 | 55.7 | 75.9 | 182 | 57.6 | 97.87 ± 12.04 | 72.4 | 203 | 59.2 | 65 | 74.4 |
| Sn | mg/kg TS | 325 | 117 | 91.8 | 173 | 53.2 | 143 | 133.5 ± 132.2 | 160 | 462 | 58.2 | 92.9 | 49.4 |
| Sr | mg/kg TS | 388 | 494 | 333 | 351 | 391 | 348 | 378.4 ± 30.97 | 352 | 422 | 361 | 336 | 833 |
| V | mg/kg TS | 34.3 | 52.8 | 43.1 | 48.4 | 53.3 | 37.4 | 46.4 ± 5.429 | 47.7 | 56.1 | 58.4 | 40 | 36.2 |
| Zn | mg/kg TS | 2480 | 5240 | 2540 | 3660 | 3250 | 3750 | 2872.8 ± 502 | 3420 | 10600 | 2690 | 4900 | 3340 |
| $SiO_2$ | % TS | 50.5 | 43.0 | 45.7 | 47.5 | 39.4 | 47.4 | 48.79 ± 1.51 | 46.7 | 40.2 | 45.6 | 47.6 | 44.9 |
| $Al2O_3$ | % TS | 11.7 | 12.2 | 14.2 | 11.7 | 20.1 | 13.0 | 12.26 ± 0.78 | 11.6 | 10.8 | 14.3 | 12.6 | 13.2 |
| CaO | % TS | 13.2 | 13.4 | 15.7 | 14.0 | 16.2 | 13.7 | 15.70 ± 0.39 | 15 | 11.4 | 16 | 14.4 | 15 |
| $Fe_2O_3$ | % TS | 7.76 | 17.2 | 9.24 | 9.42 | 10.2 | 7.97 | 10.76 ± 1.03 | 10.9 | 20.9 | 9.73 | 8.57 | 9.97 |
| $K_2O$ | % TS | 1.56 | 1.26 | 1.28 | 1.35 | 1.21 | 1.57 | 1.11 ± 0.096 | 1.48 | 1.11 | 1.16 | 1.36 | 1.43 |
| MgO | % TS | 1.89 | 2.11 | 2.21 | 1.99 | 2.11 | 1.9 | 2.19 ± 0.113 | 1.83 | 1.87 | 2.21 | 1.9 | 1.94 |
| MnO | % TS | 0.115 | 0.178 | 0.151 | 0.128 | 0.13 | 0.104 | 0.14 ± 0.021 | 0.149 | 0.184 | 0.122 | 0.115 | 0.173 |
| $Na_2O$ | % TS | 5.41 | 4.19 | 4.63 | 4.68 | 3.35 | 4.53 | 3.98 ± 0.269 | 4.33 | 3.74 | 4.19 | 5.83 | 4.67 |
| $P_2O_5$ | % TS | 1.58 | 1.51 | 1.47 | 1.46 | 1.35 | 1.6 | 1.32 ± 0.09 | 1.34 | 0.976 | 1.23 | 1.46 | 1.21 |
| $TiO_2$ | % TS | 0.995 | 1.04 | 1.36 | 1.14 | 1.58 | 1.21 | 1.34 ± 0.059 | 0.966 | 0.972 | 1.26 | 1.07 | 1.1 |
| TOC | % TS | 1.3 | 1.0 | 0.4 | 0.7 | 1.2 | 2.3 | 0.61 ± 0.195 | 0.6 | 0.4 | 0.5 | 0.7 | 1.2 |
| Cl | % TS | 0.9 | 1.3 | 1.3 | 1.1 | 0.9 | 0.7 | 1.73 ± 0.345 | 0.7 | 1.2 | 1.5 | 2.3 | 1.0 |
| F | % TS | 0.04 | 0.07 | 0.06 | 0.01 | 0.07 | 0.04 | 0.049 ± 0.007 | 0.04 | 0.05 | 0.06 | 0.1 | 0.12 |
| LOI | % TS | 2.4 | 0.6 | 1.4 | 3.0 | 1.8 | 4.2 | 0.929 ± 0.795 | 2.5 | 1.2 | 1.5 | 2.6 | 2.6 |
| TS | % | 98.8 | 95.5 | 97.8 | 97.0 | 98.3 | 97.9 | 96.44 ± 2.319 | 96.6 | 98.9 | 98 | 98.6 | 95.7 |

[a] Mean values and STD obtained from separately treated bottom ash samples generated in the experiment with PVC ($n$ = 7).

**Table VII-3.** Leaching data from the FASAN experiments: Cumulative release from "OC" bottom ash samples determined in CEN 12457-1 L/S 2 l/kg batch experiments with fresh, naturally aged at AFATEK A/S (natural), and lab-scale aged (lab) bottom ashes. Values indicated in italic reflect detection limits.

| | | **Reference** | | | **Min $O_2$** | | | **Max $O_2$** | | | **Dec. sec.** | | | **Inc. sec.** | | | **Undefined** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | fresh | natural | lab | fresh | natural | lab | fresh | natural | lab | fresh | natural | lab | fresh | natural | lab | fresh | natural | lab |
| pH | - | 11.35 | 11.35 | 9.44 | 11.38 | 11.09 | 9.45 | 11.34 | 11.41 | 9.24 | 11.32 | 11.31 | 9.21 | 11.03 | 11.22 | 10.03 | 11.19 | - | 9.70 |
| EC | mS/cm | 5.11 | 3.71 | 4.96 | 7.00 | 5.03 | 5.23 | 6.22 | 4.38 | 6.05 | - | 4.27 | 6.57 | 6.52 | 4.97 | 6.38 | 5.73 | - | 5.81 |
| As | µg/kg | 9.7 | 13.4 | 2.7 | 6.3 | 3.1 | 3.3 | 13.3 | 2.7 | 3.6 | 7.9 | 3.7 | 5.0 | 7.5 | 5.2 | 5.5 | 10.0 | - | 5.5 |
| Ba | mg/kg | 0.07 | 0.02 | 0.13 | 0.41 | 0.10 | 0.27 | 0.12 | 0.03 | 0.16 | 0.09 | 0.04 | 0.17 | 0.18 | 0.09 | 0.20 | 0.22 | - | 0.23 |
| Be | µg/kg | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | - | *1.1* |
| Cd | µg/kg | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | - | *0.2* |
| Cl | mg/kg | 1630 | 1190 | - | 2112 | 1741 | - | 1632 | 1380 | - | 1655 | 1360 | - | 2070 | 2088 | - | 1343 | - | - |
| Co | µg/kg | 0.9 | *0.4* | 0.8 | *0.4* | *0.4* | *0.4* | 0.7 | 0.4 | 1.2 | 1.7 | *0.4* | 0.8 | *0.4* | *0.4* | *0.4* | 1.0 | - | 1.0 |
| Cr | µg/kg | 39.5 | *0.2* | 353 | 9.9 | 17.3 | 65.2 | 108 | 79.8 | 816 | 48.2 | 26.8 | 358 | 19.9 | 76.3 | 414 | 32.5 | - | 193 |
| Cu | mg/kg | 9.01 | *0.003* | 2.43 | 4.64 | 1.41 | 1.43 | 5.66 | 1.68 | 1.40 | 5.96 | 1.42 | 1.63 | 2.07 | 0.98 | 0.70 | 10.3 | - | 2.63 |
| DOC | mg/kg | 437 | 46.9 | 226 | 281 | 57.8 | 105 | 257 | 51.5 | 97.8 | 310 | 70.8 | 124 | 220 | 88.8 | 93.6 | 666 | - | 408 |
| Mo | mg/kg | 0.57 | *0.001* | 0.83 | 0.18 | 0.6 | 0.64 | 0.41 | 0.44 | 0.44 | 0.38 | 0.47 | 0.60 | 0.38 | 0.43 | 0.66 | 0.47 | - | 0.50 |
| Ni | µg/kg | 26.2 | *0.2* | 12.6 | 19.4 | 8.2 | 18.0 | 15.2 | 10.8 | 28.2 | 13.7 | 8.7 | 24.7 | 7.1 | 4.0 | 5.1 | 27.1 | - | 20.1 |
| Pb | µg/kg | 59.4 | *0.2* | 2.8 | 119 | 2.1 | 3.7 | 39.0 | 10.9 | 0.7 | 22.3 | 4.7 | *0.1* | 26.3 | 9.8 | 6.4 | 1162 | - | 19.5 |
| S | mg/kg | 178 | 147 | 457 | 106 | 214 | 365 | 268 | 192 | 1087 | 303 | 197 | 1097 | 214 | 142 | 673 | 360 | - | 985 |
| Sb | µg/kg | 45.3 | *0.8* | 107 | 36.0 | 48.7 | 131.1 | 48.9 | 21.0 | 90.7 | 46.2 | 27.9 | 109 | 71.6 | 31.0 | 94.3 | 80.1 | - | 130 |
| Sn | µg/kg | 3.7 | *0.5* | 5.6 | 1.3 | 3.6 | 2.1 | 2.7 | 2.3 | 1.0 | 1.5 | 1.7 | 2.3 | 0.7 | 2.1 | 1.2 | 1.9 | - | 5.1 |
| Sr | mg/kg | 0.98 | *0.003* | 1.40 | 1.24 | 0.81 | 2.01 | 1.51 | 0.77 | 3.30 | 1.38 | 0.64 | 3.27 | 2.84 | 1.55 | 3.85 | 2.16 | - | 3.22 |
| V | µg/kg | 4.1 | *0.3* | 2.5 | 0.4 | 6.4 | 2.2 | 8.0 | 9.7 | 2.1 | 2.5 | 9.3 | 2.7 | 2.0 | 13.6 | 5.1 | 4.0 | - | 3.6 |
| Zn | µg/kg | 122 | *2.7* | 175 | 221 | 35.7 | 68.0 | 121 | 47.3 | *2.7* | 138 | 47.5 | *2.7* | 101 | 43.1 | *2.7* | 139 | - | 38.8 |

**Table VII-4.** Leaching data from the FASAN experiments: Cumulative release from "WI" bottom ash samples determined in CEN 12457-1 L/S 2 l/kg batch experiments with fresh, naturally aged at AFATEK A/S (natural), and lab-scale aged (lab) bottom ashes. Values indicated in italic reflect detection limits.

| | | PVC | | | Imp. wood | | | Shredder | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | fresh | natural | lab | fresh | natural | lab | fresh | natural | lab |
| pH | - | 11.69 ± 0.15 | 11.29 ± 0.16 | 9.65 ± 0.10 | 11.57 | 11.31 | 9.29 | 11.03 | 11.05 | 9.80 |
| EC | mS/cm | 7.82 ± 0.86 | 5.50 ± 0 | 8.20 ± 0.41 | 5.72 | 3.90 | 7.40 | 4.68 | 4.34 | 6.37 |
| As | µg/kg TS | 5.0 ± 0.2 | 4.60 ± 0.3 | 6.10 ± 1.7 | 3.11 | 3.90 | 6.20 | 9.19 | 4.30 | 5.10 |
| Ba | mg/kg TS | 6.94 ± 2.47 | 1.13 ± 0.07 | 0.21 ± 0.03 | 0.06 | 0.05 | 0.12 | 0.42 | 0.19 | 0.20 |
| Be | µg/kg TS | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* |
| Cd | µg/kg TS | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* |
| Cl | mg/kg TS | 2703 ± 332 | 2440 ± 683 | - | 1407 | 1240 | - | 1535 | 1546 | - |
| Co | µg/kg TS | 1.45 ± 0.7 | 0.40 ± 0.20 | 4.9 ± 8.6 | 2.81 | 0.70 | 2.50 | *0.4* | *0.4* | *0.4* |
| Cr | µg/kg TS | 32.1 ± 6.5 | 46.2 ± 10.1 | 609 ± 75.0 | 410 | 117 | 1131 | 13.5 | 13.7 | 16.4 |
| Cu | mg/kg TS | 1.66 ± 0.51 | 0.97 ± 0.7 | 1.26 ± 0.27 | 5.44 | 1.40 | 1.63 | 1.72 | 0.64 | 0.72 |
| DOC | mg/kg TS | 148 ± 17.5 | 43.0 ± 5.2 | 60.9 ± 19.7 | 20.0 | 75.3 | 55.3 | 152 | 41.6 | 34.8 |
| Mo | mg/kg TS | 0.20 ± 0.04 | 0.21 ± 0.06 | 0.36 ± 0.03 | 0.55 | 0.38 | 0.50 | 1.28 | 0.71 | 1.02 |
| Ni | µg/kg TS | 12.1 ± 4.6 | 7.20 ± 1.1 | 21.9 ± 22.2 | 61.5 | 9.90 | 9.90 | 5.33 | 4.60 | 3.90 |
| Pb | µg/kg TS | 574 ± 206 | 32.5 ± 14.6 | 6.5 ± 3.1 | 56.1 | 10.5 | 0.50 | 5.16 | 6.0 | *0.2* |
| S | mg/kg TS | 15.4 ± 7.3 | 50.7 ± 3.3 | 702 ± 322 | 396 | 252 | 1500 | 218 | 201 | 997 |
| Sb | µg/kg TS | 21.1 ± 5.7 | 34.5 ± 3.2 | 101 ± 16.1 | 23.9 | 18.8 | 123 | 99.3 | 48.9 | 197 |
| Sn | µg/kg TS | 39.8 ± 5.1 | 48.9 ± 9.0 | 420 ± 46.6 | 310 | 104 | 686 | 40.2 | 30.9 | 33.7 |
| Sr | mg/kg TS | 6.05 ± 4.4 | 4.25 ± 0.31 | 4.59 ± 0.54 | 1.27 | 0.97 | 4.47 | 2.03 | 0.90 | 3.14 |
| V | µg/kg TS | 1.93 ± 0.4 | 5.50 ± 1.7 | 3.90 ± 1.4 | 28.0 | 13.0 | 3.20 | 10.3 | 13.3 | 4.40 |
| Zn | µg/kg TS | 380 ± 225 | 87.5 ± 50.0 | 47.8 ± 72.1 | 220 | 96.7 | 8.10 | 220 | 41.5 | *2.5* |

**Table VII-5.** Data from the FASAN experiments: Cumulative release from "WI" bottom ash samples determined in CEN 12457-1 L/S 2 l/kg batch experiments with fresh, naturally aged at AFATEK A/S (natural), and lab-scale aged (lab) bottom ashes. Values indicated in italic reflect detection limits.

| | | **Shoes** | | | **Road salt** | | | **Batteries** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | fresh | natural | lab | fresh | natural | lab | fresh | natural | lab |
| pH | - | 11.40 | 11.33 | 9.53 | 11.49 | 11.32 | 9.83 | 10.88 | 10.56 | 9.16 |
| EC | mS/cm | 6.80 | 6.27 | 8.78 | 13.31 | 7.46 | 11.55 | 6.02 | 6.15 | 7.50 |
| As | µg/kg TS | 12.42 | 6.80 | 3.80 | 3.92 | 5.10 | 4.0 | 3.20 | 6.40 | 39.4 |
| Ba | mg/kg TS | 0.21 | 0.11 | 0.20 | 0.13 | 0.07 | 0.22 | 0.19 | 0.13 | 0.18 |
| Be | µg/kg TS | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* | *1.1* |
| Cd | µg/kg TS | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* |
| Cl | mg/kg TS | 2455 | 2380 | - | 4717 | 3142 | - | 2084 | 1979 | - |
| Co | µg/kg TS | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | 32.8 | 3.60 | 20.9 |
| Cr | µg/kg TS | 64.1 | 54.1 | 514 | 26.8 | 31.0 | 348 | 68.2 | 48.2 | 116 |
| Cu | mg/kg TS | 2.15 | 1.50 | 0.56 | 3.0 | 2.32 | 0.72 | 6.58 | 1.32 | 2.05 |
| DOC | mg/kg TS | 136 | 69.9 | 39.8 | 223 | 59.3 | 75.2 | 397 | 59.7 | 113 |
| Mo | mg/kg TS | 0.27 | 0.52 | 0.46 | 0.51 | 0.43 | 0.55 | 0.83 | 0.46 | 0.76 |
| Ni | µg/kg TS | 9.71 | 13.3 | 1.20 | 1.10 | 11.4 | 19.2 | 58.8 | 9.50 | *0.2* |
| Pb | µg/kg TS | 16.85 | 11.4 | *0.2* | 113 | 42.5 | *0.2* | 9.14 | 5.20 | *0.2* |
| S | mg/kg TS | 169 | 193 | 1202 | 614 | 150 | 665 | 524 | 750 | 1557 |
| Sb | µg/kg TS | 43.2 | 45.7 | 76.3 | 59.0 | 50.4 | 97.8 | 15.6 | 14.0 | 147 |
| Sn | µg/kg TS | 76.7 | 61.3 | 364 | 111 | 45.2 | 259 | 2.0 | *0.5* | *0.5* |
| Sr | mg/kg TS | 2.70 | 1.45 | 4.42 | 1.41 | 0.69 | 3.63 | 3.98 | 3.22 | 5.37 |
| V | µg/kg TS | 4.54 | 15.7 | 4.30 | 4.03 | 7.60 | 3.0 | 11.0 | 9.50 | 4.60 |
| Zn | µg/kg TS | 160 | 90.4 | *2.5* | 120 | 118 | 2.50 | 50.0 | 31.8 | 3.20 |

**Table VII-6.** Raw leaching data from different Danish fly ash/APC residues obtained in CEN 12457-1 batch test (L/S 2 L/kg). Leaching expressed in mg/L. Values indicated in italic reflect detection limits.

| mg/L | **VF (FA)** LS2 S1 | **NF (FA)** LS2 S2 | **Aarhus (APC)** LS2 S3 | **AF (APC)** LS2 S4 | **Aarhus (FA)** LS2 S5 | **Odense (FA)** LS2 S6 | **Kara (FA)** LS2 S7 |
|---|---|---|---|---|---|---|---|
| Al | 5.02E-01 | 5.97E-01 | 5.44E-01 | 9.61E-01 | 1.52E+00 | 4.66E-01 | 8.99E-01 |
| As | 3.70E-02 | *4.00E-04* | 8.53E-02 | 9.14E-02 | 1.39E-01 | *4.00E-04* | 1.11E-01 |
| Ba | 8.67E-01 | 5.72E-01 | 4.99E+00 | 3.03E+01 | 9.17E-01 | 6.97E-01 | 1.40E+01 |
| Be | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* |
| Ca | 2.32E+03 | 1.77E+03 | 1.48E+04 | 4.57E+04 | 1.67E+03 | 1.39E+03 | 1.89E+04 |
| Cd | 2.18E-01 | 3.81E-02 | *1.00E-04* | 2.09E-01 | 1.19E+00 | 2.82E-01 | 2.52E-02 |
| Co | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* |
| Cr | 1.00E-04 | 3.25E+00 | 2.67E-01 | 2.60E-02 | 5.39E+00 | 3.08E+00 | 1.09E-02 |
| Cu | 5.49E-01 | *5.80E-04* | *5.80E-04* | 5.99E-01 | 2.00E-01 | *5.80E-04* | 1.16E+00 |
| Fe | 6.97E-02 | *2.80E-04* | *2.80E-04* | 6.59E-01 | 2.52E-01 | *2.80E-04* | 1.92E-01 |
| K | 2.88E+04 | 2.44E+04 | 1.42E+04 | 1.78E+04 | 4.27E+04 | 3.71E+04 | 2.37E+04 |
| Li | 3.55E+00 | 6.96E-01 | 1.44E+00 | 4.82E-01 | 5.00E+00 | 2.69E+00 | 2.26E+00 |
| Mg | 1.09E-01 | 3.13E-01 | 2.26E-01 | 1.26E+00 | 6.33E-01 | 1.82E-01 | 3.27E-01 |
| Mn | *7.00E-05* | *7.00E-05* | *7.00E-05* | 8.30E-03 | 1.95E-02 | *7.00E-05* | 3.00E-02 |
| Mo | 3.17E+00 | 2.29E+00 | 2.89E-01 | 4.58E-01 | 6.41E+00 | 4.21E+00 | 8.07E-01 |
| Na | 2.10E+04 | 1.81E+04 | 1.57E+04 | 1.34E+04 | 3.22E+04 | 2.71E+04 | 1.81E+04 |
| Ni | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* |
| P | 4.16E-01 | 4.52E-01 | 4.56E-01 | 8.37E-01 | 7.93E-01 | 3.43E-01 | 4.53E-01 |
| Pb | 1.09E+01 | 2.22E-01 | 2.11E+02 | 1.03E+03 | 1.54E+00 | 9.26E-01 | 4.26E+02 |
| S | 1.40E+03 | 1.49E+03 | 3.98E+02 | 1.45E+02 | 1.68E+03 | 2.11E+03 | 3.49E+02 |
| Sb | *4.00E-04* | *4.00E-04* | 4.86E-02 | 3.71E-01 | 4.47E-01 | 5.62E-02 | 1.83E-01 |
| Se | 3.32E-01 | 2.13E-01 | 1.54E-01 | 2.98E-01 | 7.04E-01 | 4.11E-01 | *1.35E-03* |
| Si | 5.08E-01 | 8.29E-01 | 2.01E-01 | 2.78E-01 | 1.44E+00 | 2.95E-01 | 2.21E-01 |
| Sn | 2.74E-02 | *2.70E-04* | *2.70E-04* | *2.70E-04* | 1.91E-01 | 4.02E-02 | 6.70E-02 |
| Sr | 1.92E+01 | 2.13E+01 | 7.13E+01 | 5.06E+01 | 1.21E+01 | 1.64E+01 | 5.00E+01 |
| Ti | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* |
| V | *1.50E-04* | *1.50E-04* | 1.98E-02 | 2.28E-02 | *1.50E-04* | *1.50E-04* | 1.97E-02 |
| Zn | 3.57E+00 | 7.89E-01 | 6.45E+00 | 4.23E+01 | 3.99E+00 | 1.43E+00 | 1.76E+01 |
| LS [L/kg] | 2.18 | 2.22 | 2.13 | 2.13 | 2.15 | 2.08 | 2.13 |
| pH [-] | 12.14 | 11.08 | 11.81 | 11.29 | 10.353 | 11.07 | 11.669 |
| c [mS/cm] | 180.5 | 154 | 139.3 | 213.6 | 246.2 | 216.6 | 196.8 |
| Cl | 69801 | 71273 | 62853 | 125755 | 102116 | 86933 | 91227 |
| DOC | 7.4 | 15.3 | 22.6 | 1.5 | 0.4 | 9.9 | 160.5 |

**Table VII-7.** Raw leaching data from different Danish fly ash/APC residues obtained in CEN 12457-4 batch test (L/S 10 L/kg). Leaching expressed in mg/L. Values indicated in italic reflect detection limits.

| mg/L | **VF (FA)** LS10 S1 | **NF (FA)** LS10 S2 | **Aarhus (APC)** LS10 S3 | **AF (APC)** LS10 S4 | **Aarhus (FA)** LS10 S5 | **Odense (FA)** LS10 S6 | **Kara (FA)** LS10 S7 | **Aarhus (FA) Dupl.** LS10 S8 |
|---|---|---|---|---|---|---|---|---|
| Al | 1.48E-01 | 1.47E-01 | 6.70E-01 | 2.23E-01 | 2.26E+00 | 4.29E-01 | 2.32E-01 | 2.20E+00 |
| As | 8.91E-03 | 8.18E-03 | 7.55E-03 | 7.77E-03 | 4.70E-02 | 1.29E-02 | 7.65E-03 | 5.17E-02 |
| Ba | 8.97E-03 | 2.33E-01 | 8.39E-01 | 2.37E+00 | 3.18E-01 | 2.91E-01 | 7.44E-01 | 4.83E-01 |
| Be | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* |
| Ca | 1.76E+03 | 1.24E+03 | 3.65E+03 | 7.45E+03 | 1.30E+03 | 1.25E+03 | 3.83E+03 | 1.30E+03 |
| Cd | 1.42E-02 | 3.19E-03 | *1.00E-04* | 5.68E-03 | 1.90E-02 | 9.59E-03 | 1.37E-03 | 1.82E-02 |
| Co | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* |
| Cr | 3.57E-01 | 6.06E-01 | 1.02E-01 | 4.50E-01 | 1.71E+00 | 7.65E-01 | 2.39E-01 | 1.63E+00 |
| Cu | 3.03E-02 | *5.80E-04* | 4.05E-02 | 1.44E-01 | *5.80E-04* | *5.80E-04* | 1.21E-01 | *5.80E-04* |
| Fe | *2.80E-04* | *2.80E-04* | *2.80E-04* | *2.80E-04* | *2.80E-04* | *2.80E-04* | *2.80E-04* | *2.80E-04* |
| K | 4.00E+03 | 3.53E+03 | 2.04E+03 | 2.51E+03 | 6.72E+03 | 5.19E+03 | 3.14E+03 | 7.35E+03 |
| Li | 7.21E-01 | 2.49E-01 | 2.36E-01 | 1.70E-01 | 1.13E+00 | 6.71E-01 | 3.80E-01 | 1.25E+00 |
| Mg | 5.00E-02 | 2.49E-01 | 3.10E-02 | 7.91E-02 | 3.89E-01 | 2.10E-01 | 4.53E-02 | 4.58E-01 |
| Mn | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* |
| Mo | 5.17E-01 | 4.07E-01 | 1.22E-01 | 2.61E-01 | 1.13E+00 | 5.92E-01 | 3.81E-01 | 1.27E+00 |
| Na | 2.89E+03 | 2.52E+03 | 2.21E+03 | 1.84E+03 | 4.47E+03 | 3.41E+03 | 2.33E+03 | 4.95E+03 |
| Ni | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* |
| P | 2.54E-01 | 1.14E-01 | 1.04E-01 | 1.96E-01 | 1.32E-01 | 9.04E-02 | 1.10E-01 | 1.63E-01 |
| Pb | 2.17E+01 | 1.86E-01 | 3.64E+01 | 5.27E+01 | 9.84E-02 | 9.15E-01 | 5.15E+01 | 9.70E-02 |
| S | 8.72E+02 | 8.31E+02 | 4.40E+02 | 2.97E+02 | 1.12E+03 | 1.14E+03 | 3.87E+02 | 1.15E+03 |
| Sb | 8.56E-03 | 4.05E-03 | 7.71E-03 | 8.51E-03 | 7.33E-02 | 2.01E-02 | 8.51E-03 | 8.33E-02 |
| Se | 3.71E-02 | 3.33E-02 | 2.36E-02 | 4.62E-02 | 1.91E-01 | 6.38E-02 | 5.11E-02 | 2.12E-01 |
| Si | 1.89E-01 | 1.16E+00 | 1.38E-02 | 6.93E-02 | 1.46E+00 | 4.05E-01 | 1.40E-02 | 1.49E+00 |
| Sn | 4.38E-03 | *2.70E-04* | *2.70E-04* | 4.66E-03 | 2.84E-03 | *2.70E-04* | *2.70E-04* | 4.34E-03 |
| Sr | 4.46E+00 | 6.62E+00 | 1.27E+01 | 7.41E+00 | 6.42E+00 | 6.11E+00 | 7.02E+00 | 6.46E+00 |
| Ti | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* |
| V | 1.57E-03 | 3.74E-03 | 2.90E-03 | 3.01E-03 | 5.74E-03 | 1.84E-03 | 2.01E-03 | 6.04E-03 |
| Zn | 2.36E+00 | 2.62E-01 | 7.69E-01 | 5.00E+00 | 1.28E-01 | 4.95E-01 | 7.31E-01 | 1.35E-01 |
| LS [L/kg] | 9.82 | 10.02 | 10.01 | 10.06 | 10.01 | 10.03 | 10.36 | 9.11 |
| pH [-] | 12.08 | 11.05 | 12.15 | 11.96 | 10.67 | 11.08 | 12.15 | 10.63 |
| c [mS/cm] | 33.4 | 25.9 | 30.2 | 44.2 | 43.2 | 34 | 37.4 | 46 |
| Cl | 9603 | 8595 | 9658 | 18179 | 14862 | 10430 | 12735 | 16208 |
| DOC | 0.3 | 2.2 | 3.8 | 1.3 | 0.1 | 0.3 | 26.8 | 0.2 |

**Table VII-8.** Raw leaching data from different Danish bottom ashes obtained in CEN 14405 column tests. Leaching expressed in mg/L. Values indicated in italic reflect detection limits.

| KARA (BA) | C1-S1 | C1-S2 | C1-S3 | C1-S4 | C1-S5 | C1-S6 | C1-S7 | C1-S8 | C1-S9 |
|---|---|---|---|---|---|---|---|---|---|
| Al | 0.7394 | 1.36275 | 2.1587 | 3.05809 | 4.1677 | 4.82269 | 5.02677 | 4.93194 | 4.79328 |
| As | 0.00674 | 0.00692 | *0.0004* | *0.0004* | 0.00489 | 0.00485 | *0.0004* | *0.0004* | *0.0004* |
| Ba | 0.04587 | 0.05612 | 0.05098 | 0.0396 | 0.04876 | 0.01945 | 0.0233 | 0.01988 | 0.02096 |
| Be | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* |
| Ca | 365.5989 | 444.8793 | 231.7298 | 144.5619 | 99.35198 | 74.54667 | 70.02644 | 60.74382 | 54.5463 |
| Cd | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* |
| Co | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* |
| Cr | 0.01666 | 0.01826 | 0.01499 | 0.01295 | 0.0127 | 0.01217 | 0.01229 | 0.01166 | 0.01036 |
| Cu | 1.04421 | 1.27337 | 0.64785 | 0.31324 | 0.19686 | 0.11123 | 0.08186 | 0.05312 | 0.04132 |
| Fe | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* |
| K | 352.2596 | 446.2251 | 239.5325 | 128.8043 | 73.94989 | 41.10255 | 29.7282 | 18.1255 | 13.28347 |
| Li | 0.00823 | 0.01399 | 0.01364 | 0.00846 | 0.00567 | 0.00409 | 0.00252 | 0.00096 | *0.00009* |
| Mg | 0.1361 | 0.1667 | 0.08631 | 0.05276 | 0.03269 | 0.02769 | 0.02214 | 0.01987 | 0.01706 |
| Mn | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* |
| Mo | 0.86713 | 1.05694 | 0.52868 | 0.28498 | 0.18707 | 0.11454 | 0.08807 | 0.06103 | 0.04675 |
| Na | 1202.249 | 1577.644 | 700.35 | 301.0309 | 172.7418 | 59.2519 | 31.99986 | 19.55715 | 11.454 |
| Ni | 0.00424 | 0.00458 | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* |
| P | 0.0758 | 0.10095 | 0.00958 | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* |
| Pb | 0.00361 | 0.00533 | 0.00588 | 0.00182 | 0.00409 | 0.00116 | 0.00335 | 2.00E-04 | 0.00581 |
| S | 453.1789 | 563.9011 | 324.0156 | 174.0742 | 116.6051 | 74.15961 | 54.05805 | 34.04923 | 25.08063 |
| Sb | 0.00575 | 0.00573 | 0.00931 | 0.01107 | 0.01187 | 0.01614 | 0.01378 | 0.01212 | 0.0157 |
| Se | 0.14316 | 0.1201 | 0.06825 | 0.05704 | 0.02188 | *0.00135* | 0.01786 | 0.02354 | *0.00135* |
| Si | 3.2877 | 4.51575 | 6.10885 | 5.67438 | 4.99187 | 4.9555 | 4.65268 | 4.60294 | 4.50579 |
| Sn | 0.01199 | 0.00412 | 0.008 | *0.00027* | 0.00388 | 0.00621 | 0.00478 | *0.00027* | 0.00482 |
| Sr | 1.56785 | 1.91069 | 0.9537 | 0.57892 | 0.44999 | 0.30137 | 0.27301 | 0.26828 | 0.24084 |
| Ti | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* |
| V | 0.01115 | 0.01561 | 0.01903 | 0.0176 | 0.01583 | 0.0143 | 0.01325 | 0.01181 | 0.01113 |
| Zn | *7.00E-05* | *7.00E-05* | *7.00E-05* | 0.00663 | 0.00246 | 0.13596 | 0.0485 | 0.03129 | 0.02578 |
| LS [L/kg] | 0.1 | 0.24 | 0.58 | 1.04 | 2.06 | 3.47 | 4.86 | 7.45 | 9.85 |
| pH [-] | 10.6 | 10.4 | 10.63 | 10.58 | 10.52 | 10.34 | 10.42 | 10.54 | 10.4 |
| c [mS/cm] | 11.3 | 10.33 | 4.25 | 2.25 | 1.29 | 0.74 | 0.597 | 0.452 | 0.4 |
| Cl | 1725.6 | 2098.3 | 978.2 | 403.4 | 139.7 | 20.5 | 9.9 | 5.5 | 5.535 |
| DOC | 70.775 | 82.188 | 60.726 | 28.437 | 16.378 | 8.716 | 6.766 | 4.514 | 4.069 |

| VF (BA) | C2-S1 | C2-S2 | C2-S3 | C2-S4 | C2-S5 | C2-S6 | C2-S7 | C2-S8 | C2-S9 |
|---|---|---|---|---|---|---|---|---|---|
| Al | 52.18394 | 54.60409 | 116.051 | 118.2116 | 59.94591 | 37.46442 | 32.4057 | 25.06284 | 21.70185 |
| As | 0.0186 | *0.0004* | *0.0004* | 0.00665 | *0.0004* | *0.0004* | *0.0004* | 0.00436 | *0.0004* |
| Ba | 0.04889 | 0.01617 | 0.01287 | 0.00283 | 0.01208 | 0.0077 | 0.01019 | 0.00549 | 0.00511 |
| Be | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* |
| Ca | 89.25114 | 86.11063 | 50.59206 | 14.77722 | 27.20501 | 51.72954 | 61.77832 | 64.66293 | 64.90796 |
| Cd | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* |
| Co | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* |
| Cr | 0.18616 | 0.19366 | 0.24313 | 0.10392 | 0.03135 | 0.02223 | 0.01854 | 0.01317 | 0.01172 |
| Cu | 1.55253 | 1.59948 | 1.5711 | 0.50751 | 0.16055 | 0.07118 | 0.06242 | 0.04193 | 0.03498 |
| Fe | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* |
| K | 281.3648 | 295.2246 | 233.0488 | 86.42543 | 52.68639 | 35.69509 | 27.39443 | 18.38049 | 15.3447 |
| Li | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* |
| Mg | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* | 0.00525 | *0.00027* | *0.00641* | *0.00027* |
| Mn | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* |
| Mo | 0.84637 | 0.89058 | 0.97715 | 0.27478 | 0.07428 | 0.04277 | 0.03152 | 0.02114 | 0.01686 |
| Na | 1560.001 | 1641.642 | 1185.754 | 309.211 | 135.789 | 40.71384 | 23.36858 | 15.323 | 10.27809 |
| Ni | 0.00218 | 0.00253 | 0.00232 | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* |
| P | 1.43206 | 0.1864 | 0.24189 | 0.05525 | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* |
| Pb | 0.03514 | 0.00764 | 0.01394 | 0.00992 | 0.00993 | 0.00704 | 0.00691 | 0.00221 | 0.00284 |
| S | 159.8906 | 167.3342 | 200.8363 | 84.27351 | 29.14246 | 22.14479 | 21.42365 | 18.5781 | 17.51892 |
| Sb | 0.01919 | 0.02415 | 0.0382 | 0.04569 | 0.02667 | 0.02227 | 0.01918 | 0.01838 | 0.01957 |
| Se | 0.07674 | 0.04845 | 0.08064 | 0.04052 | 0.01471 | 0.02689 | 0.02066 | *0.00135* | *0.00135* |
| Si | 0.89605 | 0.89054 | 1.29188 | 1.55522 | 1.31967 | 0.97828 | 1.00302 | 1.09374 | 1.2696 |
| Sn | *0.00027* | *0.00027* | 0.00027 | 0.00645 | 0.00701 | *0.00027* | 0.00326 | *0.00027* | *0.00027* |
| Sr | 0.11716 | 0.11905 | 0.06953 | 0.01913 | 0.04146 | 0.08401 | 0.10158 | 0.10305 | 0.10399 |
| Ti | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* |
| V | 0.00446 | 0.00445 | 0.00929 | 0.01139 | 0.00617 | 0.00426 | 0.00399 | 0.00387 | 0.00379 |
| Zn | 0.02346 | 0.01031 | 0.02972 | 0.04014 | 0.02128 | 0.11001 | 0.02114 | 0.11884 | 0.0126 |
| LS [L/kg] | 0.13 | 0.28 | 0.63 | 1.1 | 2.13 | 3.53 | 4.92 | 7.52 | 10.02 |
| pH [-] | 11.21 | 11.11 | 11.27 | 11.13 | 10.86 | 10.55 | 10.53 | 10.62 | 10.52 |
| c [mS/cm] | 10.76 | 10.6 | 6.35 | 2.15 | 1.01 | 0.63 | 0.576 | 0.505 | 0.484 |
| Cl | 2452.9 | 2533.7 | 1538.6 | 132.3 | 11.8 | 11.8 | - | - | - |
| DOC | 84.144 | 86.258 | 70.229 | 19.825 | 7.518 | 4.822 | 4.195 | 2.878 | 3.187 |

| NF (BA) | C3-S1 | C3-S2 | C3-S3 | C3-S4 | C3-S5 | C3-S6 | C3-S7 | C3-S8 | C3-S9 |
|---|---|---|---|---|---|---|---|---|---|
| Al | 29.63286 | 32.02439 | 67.29694 | 50.51087 | 3.9081 | 27.31062 | 20.5691 | 15.62171 | 13.35506 |
| As | 0.0081 | *0.0004* | *0.0004* | 0.00491 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Ba | 0.01003 | 0.00925 | 0.00547 | *0.00027* | 0.02285 | 0.0111 | 0.00414 | 0.00346 | 0.00377 |
| Be | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* |
| Ca | 63.48091 | 64.80472 | 27.33345 | 18.98434 | 453.4785 | 38.94226 | 46.66599 | 49.39505 | 51.2814 |
| Cd | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* |
| Co | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* |
| Cr | 0.214 | 0.2261 | 0.16257 | 0.065 | *1.00E-04* | 0.02296 | 0.01655 | 0.01287 | 0.01089 |
| Cu | 1.12494 | 1.2007 | 0.76204 | 0.25918 | 0.13248 | 0.06474 | 0.04281 | 0.02272 | 0.01638 |
| Fe | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* | *2.70E-04* |
| K | 288.1251 | 290.6512 | 192.0727 | 92.08999 | 34.68568 | 37.73905 | 26.56477 | 18.3684 | 15.02591 |
| Li | *0.00009* | *0.00009* | *0.00009* | *0.00009* | 0.15075 | *0.00009* | *0.00009* | *0.00009* | *0.00009* |
| Mg | *0.00027* | *0.00027* | *0.00027* | *0.00027* | 0.9933 | 0.00582 | 0.00796 | 0.00467 | *0.00027* |
| Mn | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | 0.00339 | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* |
| Mo | 0.68468 | 0.73618 | 0.41639 | 0.13694 | 0.03822 | 0.02267 | 0.01543 | 0.01189 | 0.00928 |
| Na | 1398.765 | 1404.388 | 753.8094 | 262.7055 | 188.1946 | 66.81817 | 35.02582 | 24.74465 | 15.33893 |
| Ni | 0.00149 | 0.00119 | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* |
| P | 0.17797 | 0.19068 | 0.09536 | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* |
| Pb | 0.00758 | 0.00381 | 0.0096 | 0.00938 | 0.00221 | 0.00287 | 0.00487 | 0.00579 | 0.00176 |
| S | 246.6186 | 247.9519 | 200.9798 | 89.44139 | 433.7441 | 32.98371 | 25.36746 | 19.34042 | 17.95148 |
| Sb | 0.02007 | 0.02545 | 0.03676 | 0.03661 | 0.02606 | 0.02259 | 0.01911 | 0.01626 | 0.01842 |
| Se | 0.05401 | 0.05896 | 0.05567 | 0.03149 | *0.00135* | 0.01817 | *0.00135* | 0.01527 | *0.00135* |
| Si | 1.0527 | 1.17072 | 1.80654 | 2.18779 | 0.38745 | 1.75787 | 1.67839 | 1.79265 | 1.96142 |
| Sn | 0.00794 | *0.00027* | *0.00027* | 0.0044 | 0.00403 | 0.0028 | *0.00027* | *0.00027* | 0.00371 |
| Sr | 0.18536 | 0.19827 | 0.09247 | 0.06975 | 0.74081 | 0.1581 | 0.20693 | 0.25527 | 0.28593 |
| Ti | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* |
| V | 0.00837 | 0.00982 | 0.01796 | 0.01352 | 0.00321 | 0.00678 | 0.00565 | 0.00576 | 0.00591 |
| Zn | 0.01317 | 0.00947 | 0.02235 | 0.02897 | 0.30055 | 0.18516 | 0.04634 | 0.17549 | 0.01007 |
| LS [L/kg] | 0.12 | 0.27 | 0.62 | 1.09 | 2.13 | 3.56 | 4.96 | 7.56 | 10.02 |
| pH [-] | 11.19 | 11.18 | 11.27 | 11 | 10.85 | 10.64 | 10.57 | 10.59 | 10.32 |
| c [mS/cm] | 9.73 | 9.24 | 4.4 | 1.95 | 1.21 | 0.728 | 0.581 | 0.476 | 0.438 |
| Cl | 1959.3 | 2113.5 | 881.9 | 185.7 | 45.8 | 8.5 | 6.2 | 5.2 | - |
| DOC | 68.956 | 72.321 | 40.166 | 14.564 | 8.646 | 4.482 | 3.39 | 2.857 | 2.566 |

| Aa (BA-ovn3) | C4-S1 | C4-S2 | C4-S3 | C4-S4 | C4-S5 | C4-S6 | C4-S7 | C4-S8 | C4-S9 |
|---|---|---|---|---|---|---|---|---|---|
| Al | 1.9E+00 | 2.4E+00 | 3.5E+00 | 3.5E+00 | 4.0E+01 | 7.2E+00 | 1.0E+01 | 1.1E+01 | 1.1E+01 |
| As | 5.1E-03 | 1.5E-02 | 8.6E-03 | 5.7E-03 | *4.0E-04* | *4.0E-04* | *4.0E-04* | *4.0E-04* | *4.0E-04* |
| Ba | 3.2E-02 | 4.7E-02 | 3.3E-02 | 2.5E-02 | *2.7E-04* | 2.5E-02 | 3.8E-02 | 2.0E-02 | 1.9E-02 |
| Be | *5.5E-04* | *5.5E-04* | *5.5E-04* | *5.5E-04* | *5.5E-04* | *5.5E-04* | *5.5E-04* | *5.5E-04* | *5.5E-04* |
| Ca | 5.2E+02 | 7.5E+02 | 7.5E+02 | 6.5E+02 | 2.6E+01 | 2.1E+02 | 1.5E+02 | 9.8E+01 | 7.5E+01 |
| Cd | *1.0E-04* | *1.0E-04* | *1.0E-04* | *1.0E-04* | *1.0E-04* | *1.0E-04* | *1.0E-04* | *1.0E-04* | *1.0E-04* |
| Co | *2.2E-04* | *2.2E-04* | *2.2E-04* | *2.2E-04* | *2.2E-04* | *2.2E-04* | *2.2E-04* | *2.2E-04* | *2.2E-04* |
| Cr | *1.0E-04* | *1.0E-04* | *1.0E-04* | *1.0E-04* | 4.4E-02 | *1.0E-04* | *1.0E-04* | *1.0E-04* | *1.0E-04* |
| Cu | 3.3E-01 | 5.0E-01 | 4.2E-01 | 2.4E-01 | 1.7E-01 | 7.6E-02 | 7.2E-02 | 2.5E-02 | 2.0E-02 |
| Fe | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* |
| K | 1.7E+02 | 2.3E+02 | 1.9E+02 | 7.5E+01 | 6.3E+01 | 1.8E+01 | 1.5E+01 | 1.1E+01 | 9.7E+00 |
| Li | 1.2E-01 | 1.6E-01 | 2.1E-01 | 1.9E-01 | *9.0E-05* | 9.6E-02 | 7.9E-02 | 5.7E-02 | 4.9E-02 |
| Mg | 2.2E+00 | 3.2E+00 | 3.0E+00 | 2.2E+00 | 6.0E-03 | 3.9E-01 | 2.4E-01 | 1.3E-01 | 9.1E-02 |
| Mn | 5.0E-03 | 8.0E-03 | 7.6E-03 | 5.2E-03 | *7.0E-05* | *7.0E-05* | *7.0E-05* | *7.0E-05* | *7.0E-05* |
| Mo | 1.1E-01 | 1.7E-01 | 1.5E-01 | 6.8E-02 | 7.2E-02 | 2.2E-02 | 1.7E-02 | 1.3E-02 | 1.1E-02 |
| Na | 2.0E+03 | 2.2E+03 | 1.9E+03 | 4.6E+02 | 1.9E+02 | 5.6E+01 | 2.9E+01 | 1.9E+01 | 1.2E+01 |
| Ni | 2.8E-03 | 4.5E-03 | 4.2E-03 | *8.0E-05* | *8.0E-05* | *8.0E-05* | *8.0E-05* | *8.0E-05* | *8.0E-05* |
| P | 1.8E-01 | 2.2E-01 | 1.6E-01 | 1.1E-01 | 7.7E-02 | 7.3E-02 | 8.0E-02 | 6.4E-02 | 5.7E-02 |
| Pb | 1.8E-03 | 9.0E-04 | *9.0E-05* | *9.0E-05* | 1.2E-03 | *9.0E-05* | *9.0E-05* | *9.0E-05* | *9.0E-05* |
| S | 4.3E+02 | 6.4E+02 | 7.5E+02 | 5.8E+02 | 6.3E+01 | 1.8E+02 | 1.2E+02 | 7.2E+01 | 5.1E+01 |
| Sb | 1.8E-02 | 3.1E-02 | 3.6E-02 | 2.9E-02 | 2.4E-02 | 1.6E-02 | 2.3E-02 | 2.1E-02 | 2.4E-02 |
| Se | 3.0E-02 | 4.2E-02 | 2.1E-02 | *1.4E-03* | *1.4E-03* | *1.4E-03* | *1.4E-03* | *1.4E-03* | *1.4E-03* |
| Si | 3.4E-01 | 4.9E-01 | 5.6E-01 | 4.1E-01 | 2.0E+00 | 3.3E-01 | 3.7E-01 | 4.0E-01 | 4.9E-01 |
| Sn | *2.7E-04* | 4.1E-03 | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* | *2.7E-04* |
| Sr | 1.5E+00 | 2.3E+00 | 2.0E+00 | 1.4E+00 | 1.0E-01 | 4.0E-01 | 2.9E-01 | 2.4E-01 | 1.8E-01 |
| Ti | *5.0E-05* | *5.0E-05* | *5.0E-05* | *5.0E-05* | *5.0E-05* | *5.0E-05* | *5.0E-05* | *5.0E-05* | *5.0E-05* |
| V | 2.3E-03 | 2.9E-03 | 3.3E-03 | 3.0E-03 | 1.0E-02 | 2.7E-03 | 2.5E-03 | 2.4E-03 | 2.5E-03 |
| Zn | *7.0E-05* | 3.8E-03 | *7.0E-05* | *7.0E-05* | 1.6E-01 | 3.4E-02 | 3.4E-02 | 3.0E-02 | 6.8E-03 |
| LS [L/kg] | 0.08 | 0.22 | 0.56 | 1.01 | 2.02 | 3.4 | 4.77 | 7.3 | 9.64 |
| pH [-] | 9.35 | 9.12 | 9.3 | 8.79 | 8.5 | 8.87 | 8.88 | 9.06 | 8.98 |
| c [mS/cm] | 17.88 | 17.8 | 10.23 | 4.41 | 2.16 | 1.03 | 0.726 | 0.488 | 0.372 |
| Cl | 3051.7 | 4515.8 | 2532.3 | 619.1 | 92.5 | 13.2 | 6.8 | 6.4 | - |
| DOC | 27.152 | 38 | 24.197 | 10.799 | 5.174 | 2.935 | 3.036 | 2.399 | 2.323 |

| Aa (BA-ovn2) | C5-S1 | C5-S2 | C5-S3 | C5-S4 | C5-S5 | C5-S6 | C5-S7 | C5-S8 | C5-S9 |
|---|---|---|---|---|---|---|---|---|---|
| Al | 7.71576 | 6.10729 | 11.18449 | 18.95443 | 21.64917 | 23.49007 | 23.83395 | 22.77618 | 21.73415 |
| As | 0.00585 | 0.00625 | *0.0004* | *0.0004* | 0.00454 | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Ba | 0.05586 | 0.04395 | 0.03107 | 0.02475 | 0.02995 | 0.07365 | 0.06117 | 0.04116 | 0.04292 |
| Be | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* | *5.50E-04* |
| Ca | 478.8422 | 392.9027 | 237.6397 | 96.33159 | 74.47054 | 74.94353 | 71.89002 | 62.01084 | 58.5088 |
| Cd | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* | *1.00E-04* |
| Co | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* | *2.20E-04* |
| Cr | 0.03938 | 0.0281 | 0.02304 | 0.00692 | 0.00398 | 0.0067 | 0.00953 | 0.0089 | 0.008 |
| Cu | 0.61981 | 0.49469 | 0.40639 | 0.19191 | 0.09511 | 0.1252 | 0.06099 | 0.0399 | 0.031 |
| Fe | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* | 0.12591 | *0.00027* | *0.00027* | *0.00027* |
| K | 259.7314 | 222.9158 | 159.2837 | 57.26992 | 30.62681 | 26.31322 | 18.23674 | 15.81949 | 14.8755 |
| Li | 0.00174 | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* |
| Mg | 0.21481 | 0.1576 | 0.0925 | 0.03178 | 0.01778 | 0.02385 | 0.01746 | 0.01155 | 0.00568 |
| Mn | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* | *7.00E-05* |
| Mo | 0.58082 | 0.4709 | 0.3995 | 0.1473 | 0.04738 | 0.02716 | 0.01959 | 0.01473 | 0.01176 |
| Na | 1771.786 | 1374.915 | 852.0794 | 211.3245 | 74.19478 | 26.9867 | 19.99106 | 10.20948 | 6.55019 |
| Ni | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* | *8.00E-05* |
| P | 0.24957 | 0.15378 | 0.10753 | 0.05609 | 0.04598 | 0.04523 | 0.03728 | 0.03582 | 0.02034 |
| Pb | *0.00009* | *0.00009* | *0.00009* | *0.00009* | *0.00009* | 0.00197 | *0.00009* | *0.00009* | *0.00009* |
| S | 479.9063 | 392.3902 | 366.5054 | 182.3561 | 86.51232 | 55.80879 | 46.50207 | 31.82519 | 27.35056 |
| Sb | 0.01024 | 0.00785 | 0.01326 | 0.01328 | 0.01237 | 0.01378 | 0.01243 | 0.01404 | 0.02226 |
| Se | 0.02589 | 0.03702 | 0.02662 | *0.00135* | *0.00135* | *0.00135* | *0.00135* | *0.00135* | *0.00135* |
| Si | 0.99608 | 0.76821 | 0.88432 | 0.75289 | 0.65873 | 0.61133 | 0.63073 | 0.71339 | 0.85783 |
| Sn | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* | *0.00027* |
| Sr | 1.13805 | 0.92253 | 0.54493 | 0.28313 | 0.23537 | 0.24002 | 0.24049 | 0.22392 | 0.21609 |
| Ti | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* | *5.00E-05* |
| V | 0.0071 | 0.00576 | 0.0081 | 0.00833 | 0.00643 | 0.00553 | 0.00567 | 0.00532 | 0.0056 |
| Zn | 0.0008 | 0.00079 | *7.00E-05* | *7.00E-05* | *7.00E-05* | 0.06857 | 0.09759 | 0.02536 | 0.00987 |
| LS [L/kg] | 0.16 | 0.3 | 0.64 | 1.11 | 2.13 | 3.53 | 4.92 | 7.49 | 9.85 |
| pH [-] | 9.84 | 9.7 | 10.1 | 10.11 | 9.98 | 9.83 | 9.87 | 9.98 | 9.89 |
| c [mS/cm] | 9.61 | 9.6 | 5.23 | 1.62 | 0.69 | 0.47 | 0.424 | 0.359 | 0.333 |
| Cl | 2798.4 | 2189.5 | 1147.7 | 115.8 | 11.9 | 11.9 | - | - | - |
| DOC | 35.526 | 33.177 | 24.797 | 9.744 | 4.592 | 3.628 | 3.429 | 2.982 | 2.791 |

**Table VII-9.** Raw leaching data from different Danish fly ash/APC residues obtained in CEN 14405 column tests. Leaching expressed in mg/L. Values indicated in italic reflect detection limits.

| **Aarhus (FA)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mg/L | **C1-S1** | **C1-S2** | **C1-S3** | **C1-S4** | **C1-S5** | **C1-S6** | **C1-S7** | **C1-S8** | **C1-S9** | **C1-S10** | **C1-S11** | **C1-S12** |
| Al | 0.274535 | 0.0003 | 0.0003 | 0.103021 | 0.088347 | 0.053656 | 0.034016 | 0.035167 | 0.033417 | 0.034471 | 0.035768 | 0.028511 |
| As | 0.05127 | 0.09494 | 0.0004 | 0.027368 | 0.013916 | *0.0004* | 0.008103 | 0.007548 | 0.008983 | 0.00654 | *0.0004* | 0.00768 |
| Ba | 10.70868 | 5.855589 | 3.796037 | 3.894054 | 2.497295 | 1.402275 | 0.966662 | 0.942235 | 0.849392 | 0.828741 | 0.835289 | 0.735582 |
| Be | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* |
| Ca | 2245.431 | 3561.727 | 3154.401 | 1423.465 | 845.9958 | 796.7089 | 852.2352 | 865.1537 | 854.5496 | 880.7329 | 790.2519 | 782.9487 |
| Cd | 0.122736 | 0.2433 | 0.060906 | 0.003166 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Co | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | 0.011839 | *0.0002* |
| Cr | 0.017122 | 0.01955 | 0.010019 | 0.008438 | 0.004107 | 0.001976 | 0.002364 | 0.001616 | 0.001675 | 0.001962 | 0.008614 | 0.001528 |
| Cu | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | 0.027875 | *0.0006* | *0.0006* | *0.0006* | *0.0006* | 0.011175 | *0.0006* |
| Fe | 1.60924 | 0.0003 | 0.0003 | 0.398475 | 0.018448 | 0.046492 | 0.022481 | 0.020773 | 0.022105 | 0.029708 | 0.125481 | 0.026329 |
| K | 28441.23 | 56189.77 | 45811.6 | 24135.29 | 7428.239 | 1122.977 | 94.48516 | 23.44906 | 16.55786 | 12.61954 | 9.45268 | 8.58043 |
| Li | 2.66728 | 4.10405 | 3.46297 | 1.86802 | 0.87232 | 0.356362 | 0.167814 | 0.129717 | 0.10216 | 0.080958 | 0.07307 | 0.076796 |
| Mg | 0.345614 | *0.0003* | *0.0003* | 0.025811 | 0.018545 | 0.030768 | 0.01477 | 0.012193 | 0.014859 | 0.021643 | 0.030577 | 0.043144 |
| Mn | 0.044764 | 0.006967 | *0.0001* | 0.01332 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Mo | 1.350303 | 2.98687 | 3.258154 | 2.601859 | 0.976784 | 0.290888 | 0.144038 | 0.096988 | 0.075131 | 0.057869 | 0.046669 | 0.040798 |
| Na | 27151.43 | 52844.8 | 37342.27 | 20483.07 | 3420.402 | 335.1666 | 44.78441 | 15.03045 | 8.442512 | 5.496361 | 3.797036 | 3.420918 |
| Ni | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| P | 0.454163 | 0.840751 | 0.259379 | 0.226467 | 0.039835 | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* |
| Pb | 0.82082 | 1.55272 | 0.8991 | 0.7726 | 0.45948 | 0.31221 | 0.292624 | 0.451218 | 0.459762 | 0.361656 | 0.233771 | 0.192632 |
| S | 273.6229 | 922.091 | 1722.207 | 3445.965 | 1494.731 | 680.9294 | 510.9445 | 500.6567 | 501.1247 | 541.9797 | 500.5068 | 502.7322 |
| Sb | 0.03905 | 0.04698 | 0.06281 | 0.01337 | 0.006594 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Se | 1.02059 | 1.35639 | 1.39733 | 0.84987 | 0.48283 | 0.14318 | 0.092262 | 0.074242 | 0.056907 | 0.066979 | 0.040737 | 0.063192 |
| Si | 0.75126 | 0.58505 | 0.72446 | 1.20137 | 0.92905 | 0.40096 | 0.265248 | 0.144206 | 0.104098 | 0.077998 | 0.056734 | 0.065588 |
| Sn | 0.12279 | 0.12669 | 0.09035 | 0.05285 | 0.00519 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| Sr | 8.96323 | 16.0788 | 14.12928 | 9.94331 | 5.69485 | 4.32342 | 3.51008 | 2.85992 | 2.50146 | 2.21126 | 1.92549 | 1.94331 |
| Ti | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| V | 0.01857 | 0.01457 | 0.01568 | 0.00484 | 0.00455 | 0.002765 | 0.002896 | 0.00276 | 0.003008 | 0.003113 | 0.004423 | 0.003062 |
| Zn | 0.15414 | 0.55615 | 1.18674 | 1.52046 | 1.58098 | 0.833218 | 0.838836 | 0.955363 | 1.32537 | 1.442871 | 1.245925 | 1.416175 |
| DOC | 12.147 | 12.535 | 7.518 | 5.943 | 3.363 | 1.943 | 1.185 | 1.032 | 1.714 | 1.689 | 2.044 | 2.879 |
| Cl | 84000 | 173500 | 123820 | 45910 | 7918 | 938 | 92.2 | 27.5 | 25.7 | *10* | *10* | *10* |
| pH [-] | 11.12 | 11.23 | 11.58 | 11.68 | 11.74 | 11.57 | 11.46 | 11.61 | 11.61 | 11.50 | 11.50 | 11.30 |
| LS [L/kg] | 0.10 | 0.27 | 0.44 | 0.86 | 1.23 | 1.85 | 3.20 | 5.27 | 7.59 | 10.70 | 13.46 | 16.18 |

| **Vestforbrænding (FA)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mg/L | **C2-S1** | **C2-S2** | **C2-S3** | **C2-S4** | **C2-S5** | **C2-S6** | **C2-S7** | **C2-S8** | **C2-S9** | **C2-S10** | **C2-S11** | **C2-S12** |
| Al | *0.0003* | 0.047955 | *0.0003* | 0.80925 | 0.45647 | 0.375633 | 0.217852 | 0.119638 | 0.089519 | 0.065213 | 0.053345 | 0.088349 |
| As | 0.047474 | 0.034752 | *0.0004* | 0.019125 | 0.008446 | 0.004641 | 0.004851 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | 0.005423 |
| Ba | 3.904136 | 2.473766 | 2.799065 | 3.168534 | 2.58652 | 0.624123 | 0.580963 | 0.53613 | 0.558272 | 0.702832 | 0.533468 | 0.479112 |
| Be | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* |
| Ca | 795.3121 | 2113.869 | 2541.634 | 1842.545 | 1054.215 | 805.0188 | 755.4229 | 745.5506 | 751.9051 | 754.1114 | 743.7279 | 736.5637 |
| Cd | 0.659592 | 1.906476 | 1.202374 | 0.072102 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Co | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | 0.004279 |
| Cr | 1.642237 | 3.36726 | 4.043467 | 3.563539 | 1.390803 | 0.792383 | 0.671946 | 0.522703 | 0.451521 | 0.368833 | 0.303959 | 0.275182 |
| Cu | *0.0006* | *0.0006* | *0.0006* | *0.0006* | 0.010476 | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | 0.006715 |
| Fe | *0.0003* | *0.0003* | *0.0003* | 0.020691 | 0.021134 | 0.022949 | 0.023608 | 0.024979 | 0.029107 | 0.023887 | 0.023267 | 0.048157 |
| K | 30783.2 | 65262.09 | 68055.56 | 31516.38 | 4483.251 | 413.3488 | 44.62932 | 21.5223 | 17.57719 | 13.29115 | 10.44853 | 10.65261 |
| Li | 0.04449 | 0.18381 | 0.34511 | 0.8606 | 0.86303 | 0.477883 | 0.304549 | 0.208438 | 0.165989 | 0.168077 | 0.128254 | 0.126012 |
| Mg | *0.0003* | *0.0003* | *0.0003* | 0.065072 | 0.090141 | 0.064352 | 0.080487 | 0.099763 | 0.111161 | 0.120391 | 0.13081 | 0.13186 |
| Mn | 0.017997 | 0.009083 | 0.009041 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Mo | 2.34679 | 3.897401 | 4.44337 | 3.160038 | 1.287196 | 0.695959 | 0.206576 | 0.112278 | 0.080547 | 0.057967 | 0.047597 | 0.043853 |
| Na | 40652.47 | 73225 | 51737.73 | 20880.52 | 2079.946 | 193.3141 | 39.42932 | 18.72147 | 13.22851 | 9.225006 | 7.690669 | 8.183828 |
| Ni | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| P | *0.0014* | *0.0014* | *0.0014* | 0.049567 | 0.015473 | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* |
| Pb | 0.13303 | 0.64972 | 0.49857 | 0.14416 | 0.04009 | 0.042017 | 0.020198 | 0.018566 | 0.018141 | 0.031966 | 0.037475 | 0.044274 |
| S | 505.8604 | 884.3904 | 1035.832 | 1339.626 | 650.8582 | 523.3971 | 531.4449 | 527.8207 | 526.055 | 527.1148 | 520.049 | 513.6312 |
| Sb | 0.08938 | 0.05591 | 0.1071 | 0.013 | 0.00991 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Se | 1.03164 | 1.09938 | 1.20009 | 0.73688 | 0.43577 | 0.128493 | 0.072264 | 0.070602 | 0.04922 | 0.063327 | 0.042454 | 0.055074 |
| Si | 2.3635 | 1.84585 | 1.56722 | 3.13592 | 2.00313 | 1.672587 | 1.37302 | 1.416606 | 1.509174 | 1.718325 | 1.896629 | 2.029403 |
| Sn | 0.0731 | 0.054 | 0.04991 | 0.0539 | 0.01354 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| Sr | 8.95492 | 19.00274 | 18.19559 | 16.95733 | 11.30175 | 7.70446 | 4.78886 | 3.10015 | 2.56469 | 1.83622 | 1.99682 | 1.99834 |
| Ti | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| V | *0.0002* | *0.0002* | *0.0002* | 0.0018 | 0.00298 | 0.00197 | 0.002478 | 0.003059 | 0.004217 | 0.004594 | 0.004736 | 0.004796 |
| Zn | 0.15176 | 0.18506 | 0.14663 | 0.06463 | 0.03104 | 0.00776 | *0.0003* | 0.004735 | 0.005622 | 0.0059 | 0.009696 | 0.018658 |
| DOC | 18.413 | 20.672 | 17.892 | 10.118 | 4.48 | 3.177 | 1.96 | 1.439 | 1.762 | 1.6634 | 0.458 | 1.615 |
| Cl | 112390 | 230000 | 193000 | 57200 | 6113.6 | 786 | 69.7 | 44.8 | 29.4 | 30.8 | 24 | 29 |
| pH [-] | 8.92 | 10.58 | 10.76 | 11.12 | 11.10 | 10.98 | 10.84 | 11.08 | 11.14 | 11.11 | 11.16 | 10.88 |
| LS [L/kg] | 0.07 | 0.20 | 0.35 | 0.68 | 0.96 | 1.44 | 2.49 | 4.10 | 5.90 | 8.32 | 10.50 | 12.67 |

| **Amagerforbrænding (APC)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mg/L | **C3-S1** | **C3-S2** | **C3-S3** | **C3-S4** | **C3-S5** | **C3-S6** | **C3-S7** | **C3-S8** | **C3-S9** | **C3-S10** | **C3-S11** | **C3-S12** |
| Al | 0.42603 | 0.49132 | 0.39436 | 0.01786 | *0.0003* | 0.024287 | 0.031092 | 0.05066 | *0.0003* | *0.0003* | 0.007389 | *0.0003* |
| As | 0.0597 | 0.10271 | 0.09991 | 0.04189 | 0.01726 | 0.00652 | 0.00427 | 0.0004 | 0.00457 | 0.00412 | 0.00466 | 0.0004 |
| Ba | 9.118985 | 12.82241 | 13.87141 | 8.859854 | 2.983392 | 1.058942 | 0.939793 | 0.788749 | 0.625444 | 0.560341 | 0.546644 | 0.478337 |
| Be | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* |
| Ca | 15336.99 | 26748.19 | 29740.3 | 26170.97 | 8668.483 | 3001.585 | 1787.658 | 1608.977 | 1537.454 | 1522.99 | 1505.249 | 1509.997 |
| Cd | 0.006828 | 0.019172 | *0.0001* | 0.003644 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Co | 0.046156 | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* |
| Cr | 0.164078 | 0.21066 | 0.216526 | 0.191139 | 0.110549 | 0.045456 | 0.015035 | 0.002778 | 0.00168 | 0.001659 | 0.0001 | 0.00114 |
| Cu | *0.0006* | *0.0006* | *0.0006* | 0.066116 | 0.027875 | 0.009694 | 0.007349 | 0.006029 | 0.005948 | *0.0006* | *0.0006* | *0.0006* |
| Fe | 1.324405 | 0.890927 | 1.086815 | 0.100572 | 0.016207 | 0.023045 | 0.030861 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| K | 28123.32 | 46152.23 | 35494.11 | 14588.28 | 2971.604 | 374.272 | 144.4728 | 93.92492 | 81.08266 | 41.733 | 41.95912 | 32.52794 |
| Li | 1.82695 | 2.76514 | 2.6594 | 1.88138 | 1.0027 | 0.454054 | 0.247615 | 0.146816 | 0.162639 | 0.11582 | 0.108299 | 0.092841 |
| Mg | 0.060431 | 0.190515 | 0.296172 | 0.402751 | 0.061753 | 0.010898 | 0.003955 | *0.0003* | 0.002974 | *0.0003* | *0.0003* | 0.002989 |
| Mn | 0.0001 | 0.015138 | 0.018481 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Mo | 0.156817 | 0.259191 | 0.32852 | 0.298327 | 0.182706 | 0.114688 | 0.085876 | 0.06146 | 0.038113 | 0.025688 | 0.023873 | 0.024518 |
| Na | 25458.01 | 38340.3 | 28492.08 | 15369.02 | 1903.254 | 197.9345 | 43.85388 | 17.22151 | 8.917762 | 3.913758 | 3.862758 | 3.178941 |
| Ni | *0.0001* | *0.0001* | *0.0001* | 0.002841 | 0.001186 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| P | 0.143235 | *0.0014* | *0.0014* | 1.412964 | 0.033564 | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* |
| Pb | 705.4586 | 1225.307 | 1345.397 | 1028.729 | 190.7799 | 38.19748 | 15.11802 | 11.3232 | 9.3664 | 7.837 | 64.4111 | 5.7882 |
| S | 96.26787 | 173.4357 | 193.3035 | 253.4114 | 330.3488 | 361.7341 | 407.0159 | 409.6492 | 405.0829 | 400.4234 | 402.8724 | 401.894 |
| Sb | 0.21702 | 0.37826 | 0.47508 | 0.40747 | 0.07548 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Se | 0.87223 | 0.55188 | 0.79746 | 0.34959 | 0.29124 | 0.106964 | 0.099275 | 0.047482 | 0.054458 | 0.051174 | 0.032784 | 0.035403 |
| Si | 0.18987 | 0.79867 | 0.25758 | 0.41985 | 0.13704 | 0.104986 | 0.074369 | *0.0014* | 0.026997 | *0.0014* | *0.0014* | *0.0014* |
| Sn | 0.14366 | 0.09912 | 0.14585 | 0.02894 | 0.01796 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| Sr | 125.8277 | 207.2795 | 168.9215 | 81.3968 | 21.19054 | 8.07105 | 3.35106 | 2.2009 | 1.99018 | 2.10692 | 1.68748 | 1.55183 |
| Ti | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| V | 0.04859 | 0.04575 | 0.03795 | 0.00864 | 0.00509 | 0.003007 | 0.002504 | 0.002338 | 0.002822 | 0.002571 | 0.002192 | 0.002668 |
| Zn | 2.63336 | 6.69565 | 9.99494 | 12.71761 | 5.99982 | 2.839592 | 2.501677 | 2.786475 | 2.951128 | 2.862912 | 2.320256 | 2.643774 |
| DOC | 26.993 | 44.443 | 41.663 | 26.371 | 11.497 | 7.269 | 3.335 | 2.046 | 1.397 | 1.048 | 0.7786 | 2.792 |
| Cl | 105200 | 194920 | 163260 | 84060 | 18130 | 3290 | 543 | 153 | 68.8 | 35.4 | 20.4 | 19.7 |
| pH [-] | 11.24 | 11.33 | 11.41 | 11.65 | 11.88 | 12.03 | 12.05 | 12.11 | 12.17 | 12.2 | 12.37 | 12.00 |
| LS [L/kg] | 0.08 | 0.21 | 0.35 | 0.70 | 1.01 | 1.50 | 2.57 | 4.18 | 6.07 | 8.57 | 10.68 | 12.69 |

| **Aarhus (APC)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mg/L | **C4-S1** | **C4-S2** | **C4-S3** | **C4-S4** | **C4-S5** | **C4-S6** | **C4-S7** | **C4-S8** | **C4-S9** | **C4-S10** | **C4-S11** | **C4-S12** |
| Al | 83.81275 | 60.60045 | 35.9691 | 3.726449 | *0.0003* | 0.041603 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | 0.125492 | 0.007119 |
| As | 0.10361 | 0.09819 | 0.1116 | 0.0228 | 0.02294 | 0.005822 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Ba | 58.0868 | 70.66846 | 55.03336 | 28.35961 | 6.628893 | 0.964423 | 0.478318 | 0.414993 | 0.304586 | 0.305357 | 4.736383 | 0.242574 |
| Be | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* |
| Ca | 48532.23 | 70968.83 | 63590.56 | 40840.67 | 12327.46 | 2597.159 | 1450.56 | 1370.514 | 1332.156 | 1330.321 | 1247.432 | 1064.087 |
| Cd | 7.747518 | 8.316516 | 5.325048 | 1.126263 | 0.057166 | 0.005338 | 0.002846 | 0.001463 | *0.0001* | 0.001767 | 0.001397 | 0.002057 |
| Co | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* |
| Cr | 0.762475 | 0.717975 | 0.531243 | 0.106674 | 0.023906 | 0.010172 | 0.005099 | 0.002598 | 0.001515 | 0.001035 | 0.003092 | 0.0001 |
| Cu | 3.60989 | 3.630902 | 2.205035 | 0.301044 | 0.106211 | 0.031686 | 0.019406 | 0.01447 | 0.007158 | 0.011266 | 0.015124 | 0.01072 |
| Fe | 51.80614 | 41.51334 | 26.13124 | 3.296981 | *0.0003* | *0.0003* | *0.0003* | 0.005548 | 0.029783 | *0.0003* | 0.524745 | 0.026086 |
| K | 20785.13 | 32123.64 | 27186.07 | 15161.4 | 4156.222 | 349.3796 | 22.26183 | 15.26744 | 12.87964 | 10.65988 | *0.007* | *0.007* |
| Li | 0.34722 | 0.61273 | 0.80047 | 0.96452 | 1.02339 | 0.422316 | 0.174187 | 0.145606 | 0.116845 | 0.08819 | 0.060654 | 0.054233 |
| Mg | 1.498897 | 1.454441 | 1.10692 | 0.715611 | 0.088733 | 0.015583 | 0.004965 | 0.00713 | 0.0003 | 0.006381 | 0.09158 | 0.010442 |
| Mn | 0.223813 | 0.149762 | 0.07555 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | 0.034976 | *0.0001* |
| Mo | 0.118915 | 0.250409 | 0.332312 | 0.399726 | 0.419357 | 0.407709 | 0.198485 | 0.094804 | 0.076211 | 0.066073 | 0.054349 | 0.041992 |
| Na | 22341.23 | 25213.03 | 21172.75 | 16224.26 | 3101.276 | 256.6375 | 16.50227 | 9.195182 | 7.732763 | 4.906322 | 1.747641 | *0.007* |
| Ni | *0.0001* | *0.0001* | *0.0001* | 0.003876 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| P | 0.130937 | 0.130423 | 0.190365 | 0.108137 | 0.038237 | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* |
| Pb | 499.2827 | 547.576 | 361.9202 | 147.0014 | 18.13998 | 2.090542 | 1.019292 | 0.587883 | 0.411102 | 0.506265 | 0.482198 | 0.412339 |
| S | 67.59722 | 102.2021 | 155.7144 | 212.0053 | 322.3964 | 396.6193 | 447.6047 | 418.3793 | 410.6177 | 397.9925 | 350.4824 | 356.7184 |
| Sb | 0.10374 | 0.09389 | 0.12816 | 0.07555 | 0.03078 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Se | 0.53504 | 0.35247 | 0.54137 | 0.4426 | 0.45979 | 0.18495 | 0.086856 | 0.045959 | 0.052658 | 0.051392 | 0.021789 | 0.03895 |
| Si | 1.09715 | 0.87943 | 0.36914 | 0.22873 | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | 0.085957 | *0.0014* |
| Sn | 0.14383 | 0.15443 | 0.15733 | 0.09049 | 0.02585 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| Sr | 52.62001 | 80.12356 | 74.61988 | 51.51312 | 16.99698 | 4.79914 | 3.59429 | 2.88856 | 2.50476 | 2.10692 | 1.68748 | 1.55183 |
| Ti | 0.01937 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| V | 0.04377 | 0.04027 | 0.04198 | 0.02768 | 0.00618 | 0.001794 | 0.002039 | 0.002503 | 0.002469 | 0.002496 | 0.002602 | 0.002714 |
| Zn | 202.9247 | 238.8751 | 173.9101 | 112.1973 | 38.51196 | 6.92317 | 3.3161 | 2.32407 | 1.05743 | 2.02697 | 1.83968 | 1.59202 |
| DOC | 25.269 | 25.388 | 28.414 | 20.109 | 6.86 | 3.356 | 3.464 | 1.041 | 1.029 | 1.502 | 0.211 | 0.7464 |
| Cl | 156430 | 240116 | 217531 | 115900 | - | - | - | - | - | - | - | - |
| pH [-] | 10.55 | 10.62 | 10.80 | 11.19 | 11.83 | 12.00 | 12.04 | 12.03 | 12.05 | 12.11 | 12.16 | 11.95 |
| LS [L/kg] | 0.11 | 0.30 | 0.49 | 0.98 | 1.38 | 2.00 | 3.39 | 5.48 | 7.81 | 10.93 | 13.89 | 16.74 |

| **Odense (FA)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mg/L | **C5-S1** | **C5-S2** | **C5-S3** | **C5-S4** | **C5-S5** | **C5-S6** | **C5-S7** | **C5-S8** | **C5-S9** | **C5-S10** | **C5-S11** | **C5-S12** |
| Al | 1.22842 | 0.60779 | 2.0335 | 31.48327 | 40.26382 | 12.25814 | 4.863865 | 1.876452 | 0.924345 | 0.509087 | 0.371396 | 0.338854 |
| As | 0.064337 | 0.039793 | 0.047353 | 0.048769 | 0.049806 | 0.016291 | 0.011729 | 0.01246 | 0.018773 | 0.019647 | 0.01616 | 0.027684 |
| Ba | 47.53912 | 2.560714 | 2.851877 | 1.7931 | 0.994984 | 0.435878 | 0.251453 | 0.308157 | 0.320296 | 0.266768 | 0.257888 | 0.233315 |
| Be | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* |
| Ca | 867.8185 | 1998.786 | 3133.658 | 1069.416 | 586.3426 | 642.3358 | 685.1082 | 676.1734 | 686.6039 | 678.3978 | 673.3376 | 673.8416 |
| Cd | 49.95202 | 53.77328 | 11.46049 | 2.225348 | 0.012616 | 0.002229 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Co | *0.0002* | *0.0002* | *0.0002* | *0.0002* | 0.006679 | *0.0002* | 0.003246 | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* |
| Cr | 0.325196 | 0.279866 | 0.034209 | 0.096075 | 0.086826 | 0.021898 | 0.009346 | 0.00312 | 0.001237 | 0.001657 | 0.013833 | 0.035695 |
| Cu | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* |
| Fe | *0.0003* | 0.036046 | *0.0003* | *0.0003* | 0.085252 | *0.0003* | 0.027156 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| K | 29000.18 | 59019.14 | 76884.69 | 45008.87 | 13962.69 | 1326.479 | 54.12999 | 19.71715 | 10.51383 | 6.439125 | 2.884364 | 9.917589 |
| Li | 3.0604 | 2.59413 | 0.68774 | 0.55918 | 0.50477 | 0.688122 | 0.484465 | 0.307448 | 0.22339 | 0.156921 | 0.172188 | 0.16004 |
| Mg | 70.8115 | 68.64971 | 3.435646 | 1.454845 | 0.12137 | 0.076571 | 0.074817 | 0.117982 | 0.171145 | 0.229283 | 0.258897 | 0.265971 |
| Mn | 0.237819 | 0.10591 | 0.008835 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Mo | 0.69547 | 3.046465 | 4.751899 | 9.980648 | 3.536725 | 0.813197 | 0.280561 | 0.158691 | 0.118252 | 0.093785 | 0.070236 | 0.066548 |
| Na | 37655.26 | 80834.72 | 59951.78 | 23191.1 | 1417.871 | 184.5339 | 28.79993 | 12.55379 | 8.08059 | 5.787441 | 4.009126 | 5.122024 |
| Ni | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| P | 0.215737 | 0.448767 | 0.460002 | 0.255994 | 0.100067 | *0.0014* | *0.0014* | *0.0014* | *0.0014* | 0.514225 | *0.0014* | *0.0014* |
| Pb | 10.55356 | 10.94411 | 2.13203 | 0.07364 | 0.00887 | *0.0001* | 0.005378 | 0.000932 | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| S | 333.9031 | 652.5656 | 656.4822 | 3913.284 | 5677.603 | 823.9665 | 461.8747 | 446.7313 | 448.4204 | 441.7253 | 438.9664 | 434.579 |
| Sb | 1.31292 | 3.14779 | 2.42901 | 1.09397 | 0.25788 | 0.067416 | 0.020073 | 0.012264 | *0.0004* | 0.005782 | *0.0004* | 0.00599 |
| Se | 0.9855 | 1.45043 | 1.60752 | 1.39442 | 0.67423 | 0.131711 | 0.114198 | 0.07576 | 0.068443 | 0.048013 | 0.075438 | 0.051577 |
| Si | 1.52295 | 3.51178 | 0.56349 | 3.93631 | 0.48961 | 0.509779 | 1.18445 | 2.50539 | 3.369449 | 4.146848 | 4.4332 | 4.594174 |
| Sn | 0.08419 | 0.11245 | 0.11759 | 0.06327 | 0.0154 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| Sr | 6.65253 | 9.66038 | 12.05542 | 3.80232 | 5.064 | 4.87065 | 4.65405 | 3.07524 | 2.40449 | 2.00751 | 1.78126 | 1.7933 |
| Ti | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| V | 0.0149 | *0.0002* | *0.0002* | 0.00317 | 0.01108 | 0.004899 | 0.006776 | 0.008953 | 0.011499 | 0.012624 | 0.01353 | 0.014721 |
| Zn | 40.23399 | 37.78993 | 1.32515 | 0.10231 | 0.02661 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| DOC | 2.6412 | 2.897 | 1.158 | 2.989 | 7.32 | 0.028 | 0.601 | 0.3406 | 4.597 | 2.454 | 2.525 | 1.16 |
| Cl | - | - | - | - | - | - | - | - | - | - | - | - |
| pH [-] | 4.8 | 7.2 | 8.59 | 9.79 | 10.17 | 10.70 | 10.62 | 10.55 | 10.69 | 10.69 | 10.85 | 10.70 |
| LS [L/kg] | 0.09 | 0.28 | 0.48 | 0.97 | 1.38 | 2.06 | 3.61 | 5.87 | 8.42 | 11.86 | 14.99 | 17.93 |

| **Nordforbrænding (FA)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mg/L | **C6-S1** | **C6-S2** | **C6-S3** | **C6-S4** | **C6-S5** | **C6-S6** | **C6-S7** | **C6-S8** | **C6-S9** | **C6-S10** | **C6-S11** | **C6-S12** |
| Al | 5.09603 | 4.0586 | 1.00936 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | 0.012756 | 0.008934 | 0.012318 |
| As | 0.14011 | 0.11038 | 0.06483 | 0.012881 | 0.0004 | 0.0004 | 0.00467 | 0.0004 | 0.009072 | 0.005159 | 0.006363 | 0.008106 |
| Ba | 23.15929 | 32.15697 | 20.92387 | 7.332757 | 1.701976 | 0.716301 | 0.60813 | 0.578703 | 0.571488 | 0.463394 | 0.436901 | 0.401663 |
| Be | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* |
| Ca | 22436.93 | 34356.57 | 25662.69 | 10704.24 | 3026.472 | 1668.585 | 1600.518 | 1507.516 | 1495.028 | 1391.233 | 1395.587 | 1396.034 |
| Cd | 0.606342 | 0.5422 | 0.179588 | 0.011243 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Co | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* | *0.0002* |
| Cr | 0.62178 | 0.481735 | 0.220834 | 0.023647 | 0.006099 | 0.003443 | 0.00267 | 0.001428 | 0.001774 | 0.001326 | *0.0001* | 0.001355 |
| Cu | 2.593542 | 3.00514 | 1.515775 | 0.530372 | 0.086477 | 0.082792 | 0.063826 | 0.024182 | 0.028008 | 0.00913 | 0.010269 | 0.015963 |
| Fe | 15.13971 | 9.239515 | 3.230256 | 0.100108 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| K | 29478.82 | 45499.92 | 33225.56 | 11037.4 | 829.3007 | 86.12913 | 18.51031 | 15.1069 | 15.48371 | 18.22608 | 15.3039 | 11.62636 |
| Li | 2.24767 | 3.39236 | 3.01964 | 1.53009 | 0.56976 | 0.237941 | 0.175912 | 0.14919 | 0.145683 | 0.118479 | 0.125135 | 0.077805 |
| Mg | 0.282238 | 0.445645 | 0.215358 | 0.11041 | 0.003606 | 0.003582 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* |
| Mn | 0.010785 | 0.007302 | *0.0001* | 0.020448 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Mo | 0.221026 | 0.479381 | 0.468574 | 0.400659 | 0.253582 | 0.225033 | 0.261667 | 0.128453 | 0.105425 | 0.06829 | 0.062368 | 0.057946 |
| Na | 24545.05 | 38254.52 | 25913.87 | 10528.55 | 600.2462 | 83.99576 | 13.28187 | 9.3822 | 8.107261 | 7.843266 | 10.82215 | 6.285215 |
| Ni | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| P | 0.342766 | 0.243417 | *0.0014* | 2.447447 | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* |
| Pb | 609.4585 | 687.2322 | 350.082 | 80.99246 | 8.034069 | 3.212982 | 1.244698 | 0.784498 | 0.779371 | 0.607145 | 0.454159 | 0.375924 |
| S | 46.59778 | 115.1859 | 169.9963 | 254.0118 | 305.8555 | 323.617 | 424.5736 | 442.3859 | 450.2135 | 429.0303 | 415.4495 | 417.4879 |
| Sb | 0.19572 | 0.25391 | 0.07683 | 0.03053 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Se | 0.6228 | 0.62335 | 0.55025 | 0.43279 | 0.37024 | 0.151982 | 0.077093 | 0.062528 | 0.070534 | 0.064896 | 0.030611 | 0.034143 |
| Si | *0.0014* | 0.18148 | *0.0014* | 0.10898 | *0.0014* | 0.023215 | 0.024521 | *0.0014* | 0.08422 | 0.025301 | 0.014887 | 0.041647 |
| Sn | 0.0987 | 0.10956 | 0.0984 | 0.01174 | 0.08921 | *0.0003* | *0.0003* | *0.0003* | 0.005766 | 0.005744 | 0.006387 | 0.005736 |
| Sr | 55.4382 | 85.1641 | 58.72405 | 22.06697 | 6.68044 | 3.41909 | 2.41172 | 2.22287 | 2.11536 | 1.74641 | 1.82807 | 1.48338 |
| Ti | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| V | 0.03903 | 0.04013 | 0.04755 | 0.01639 | 0.01311 | 0.002519 | 0.002454 | 0.001929 | 0.003118 | 0.002993 | 0.002836 | 0.003885 |
| Zn | 80.54898 | 86.1956 | 66.67332 | 4.80627 | 4.77283 | 5.55817 | 3.04194 | 1.99105 | 3.36808 | 2.94696 | 2.92337 | 3.46099 |
| DOC | 331.5 | 532 | 343 | 151 | 44.673 | 19.976 | 7.287 | 4.583 | 3.984 | 3.846 | 3.462 | 2.201 |
| Cl | 117154.0 | 196813.0 | 130054.0 | 39616.0 | 4124.0 | 626.0 | 111.0 | 68.3 | 51.8 | 107.0 | 102.0 | 57.6 |
| pH [-] | 10.99 | 11.16 | 11.46 | 12.00 | 12.12 | 12.12 | 12.03 | 12.02 | 12.06 | 12.1 | 12.13 | 12.06 |
| LS [L/kg] | 0.12 | 0.36 | 0.60 | 1.18 | 1.69 | 2.56 | 4.47 | 7.42 | 9.83 | 14.99 | 17.72 | 20.66 |

| **KARA (FA)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mg/L | **C7-S1** | **C7-S2** | **C7-S3** | **C7-S4** | **C7-S5** | **C7-S6** | **C7-S7** | **C7-S8** | **C7-S9** | **C7-S10** | **C7-S11** | **C7-S12** |
| Al | 1.76637 | 1.07301 | 0.3645 | 2.88555 | 2.83127 | 1.109602 | 0.431055 | 0.151336 | 0.08147 | 0.073538 | 0.049307 | 0.03529 |
| As | 0.0004 | 0.07577 | 0.0004 | 0.028608 | 0.029369 | 0.011014 | 0.005762 | *0.0004* | 0.008148 | 0.006658 | 0.006599 | 0.007067 |
| Ba | 1.893152 | 2.211494 | 2.259597 | 1.350647 | *0.0014* | 0.321405 | 0.265911 | 0.293008 | 0.256311 | 0.272063 | 0.266067 | 0.378946 |
| Be | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* |
| Ca | 1251.243 | 2264.57 | 2303.452 | 1116.012 | 640.8901 | 702.7749 | 761.3362 | 769.068 | 780.4855 | 792.3329 | 774.3679 | 767.4794 |
| Cd | 0.646459 | 1.624015 | 1.030356 | 0.031111 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Co | 0.0002 | 0.0002 | 0.0002 | 0.0002 | *0.0002* | *0.0002* | *0.0002* | 0.003363 | *0.0002* | *0.0002* | *0.0002* | *0.0002* |
| Cr | 1.976437 | 1.566421 | 0.974186 | 0.235169 | 0.038163 | 0.009013 | 0.002472 | 0.003126 | *0.0001* | 0.001194 | 0.001519 | 0.0001 |
| Cu | *0.0006* | *0.0006* | *0.0006* | *0.0006* | 0.006105 | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | *0.0006* | 0.007104 |
| Fe | 0.467505 | 2.841441 | *0.0003* | *0.0003* | *0.0003* | *0.0003* | *0.0003* | 0.013534 | *0.0003* | *0.0003* | *0.0003* | 0.003883 |
| K | 36361.91 | 68141.46 | 63967.93 | 29204.42 | 10091.89 | 1278.4 | 38.8548 | 18.26802 | 12.57197 | 12.10647 | 9.12464 | 10.50978 |
| Li | 0.77268 | 1.81582 | 2.50004 | 1.98115 | 1.20373 | 0.766798 | 0.440896 | 0.259402 | 0.19488 | 0.143795 | 0.167323 | 0.118522 |
| Mg | 1.261366 | 0.56691 | *0.0003* | 0.026587 | 0.0439 | 0.088246 | 0.093283 | 0.087543 | 0.087265 | 0.085573 | 0.079939 | 0.109231 |
| Mn | 0.027732 | 0.226738 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| Mo | 1.821015 | 3.523372 | 4.822087 | 5.410548 | 2.429059 | 0.814849 | 0.288994 | 0.147655 | 0.10088 | 0.078973 | 0.073385 | 0.056024 |
| Na | 46052.97 | 70175.01 | 48216.6 | 18651.48 | 1651.129 | 198.9119 | 23.16855 | 10.86753 | 7.013543 | 5.312918 | 4.466827 | 5.704903 |
| Ni | 0.751513 | 0.017114 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| P | 0.495847 | 0.826657 | 0.272681 | 0.18385 | 0.044062 | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* | *0.0014* |
| Pb | 3.57847 | 11.6306 | 8.90746 | 3.9878 | 1.56403 | 0.77674 | 0.531734 | 0.751564 | 0.596735 | 0.433884 | 0.39156 | 0.395084 |
| S | 530.2005 | 977.9917 | 1568.961 | 5445.905 | 4551.615 | 968.6442 | 571.4159 | 568.2394 | 566.6977 | 570.1573 | 560.4871 | 555.4936 |
| Sb | 0.06796 | 0.09832 | 0.076 | 0.03654 | 0.03109 | 0.016633 | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* | *0.0004* |
| Se | 0.63396 | 0.89852 | 1.11303 | 0.7204 | 0.3935 | 0.103753 | 0.059351 | 0.058199 | 0.052477 | 0.04844 | 0.039698 | 0.034883 |
| Si | 2.99001 | 2.09274 | 0.69289 | 1.280491 | 1.319578 | 1.205152 | 1.14979 | 1.143218 | 1.065867 | 1.098238 | 1.108944 | 1.016782 |
| Sn | 0.08299 | 0.0682 | 0.08801 | 0.01578 | 0.00387 | *0.0003* | 0.005983 | *0.0003* | 0.005773 | *0.0003* | *0.0003* | *0.0003* |
| Sr | 8.17308 | 12.74248 | 11.56303 | 7.18879 | 7.27548 | 6.76801 | 4.01292 | 2.89722 | 2.52241 | 2.2978 | 2.24716 | 2.1083 |
| Ti | 1.41198 | 0.03467 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | 0.077777 | *0.0001* | *0.0001* | *0.0001* | *0.0001* |
| V | 0.0002 | 0.01271 | 0.01999 | 0.00201 | 0.00218 | 0.002825 | 0.003889 | 0.005849 | 0.005721 | 0.006172 | 0.005785 | 0.006131 |
| Zn | 0.41451 | 0.77825 | 0.96381 | 0.82285 | 0.38451 | 0.137604 | 0.057269 | 0.068359 | 0.062832 | 0.047464 | 0.049701 | 0.071433 |
| DOC | | 12.017 | 7.554 | 6.297 | 3.695 | 2.102 | 1.717 | 1.665 | 1.3001 | 1.98 | 1.533 | 1.876 |
| Cl | 120590 | 214607 | 158727 | 42242 | 4310 | 466.9 | 65.1 | 44.9 | 24.1 | 99.5 | 24 | 15.8 |
| pH [-] | 10.33 | 10.66 | 10.98 | 11.36 | 11.11 | 11.06 | 11.05 | 11.00 | 11.03 | 11.03 | 11.21 | 11.05 |
| LS [L/kg] | 0.07 | 0.27 | 0.46 | 0.95 | 1.37 | 2.06 | 3.52 | 5.80 | 8.37 | 11.42 | 13.65 | 15.93 |

| Deres betegnelse | PSO Vestfor | Reference sample BA: Vestforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085424 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| As | 43.3 | 12.3 | mg/kg TS | 1 | H |
| Ba | 1460 | 109 | mg/kg TS | 1 | E |
| Be | 1.31 | 0.34 | mg/kg TS | 1 | E |
| Cd | 1.77 | 0.36 | mg/kg TS | 1 | H |
| Co | 31.9 | 6.5 | mg/kg TS | 1 | H |
| Cr | 598 | 80 | mg/kg TS | 1 | E |
| Cu | 3050 | 437 | mg/kg TS | 1 | E |
| Hg | 0.0373 | 0.0085 | mg/kg TS | 1 | F |
| Mo | 12.8 | 4.4 | mg/kg TS | 1 | E |
| Nb | 9.48 | 5.65 | mg/kg TS | 1 | E |
| Ni | 307 | 67 | mg/kg TS | 1 | H |
| Pb | 3280 | 548 | mg/kg TS | 1 | E |
| S* | 4340 | | mg/kg TS | 1 | A |
| Sc | 1.96 | 1.31 | mg/kg TS | 1 | E |
| Sn* | 227 | | mg/kg TS | 1 | S |
| Sr | 433 | 30 | mg/kg TS | 1 | E |
| V | 51.0 | 9.0 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 12.2 | 1.7 | mg/kg TS | 1 | E |
| Zn | 3240 | 469 | mg/kg TS | 1 | E |
| Zr | 236 | 40 | mg/kg TS | 1 | E |
| SiO2 | 47.1 | 3.7 | %TS | 1 | E |
| Al2O3 | 10.3 | 0.9 | %TS | 1 | E |
| CaO | 15.6 | 1.2 | %TS | 1 | E |
| Fe2O3 | 11.9 | 1.0 | %TS | 1 | E |
| K2O | 1.24 | 0.10 | %TS | 1 | E |
| MgO | 1.95 | 0.15 | %TS | 1 | E |
| MnO | 0.134 | 0.013 | %TS | 1 | E |
| Na2O | 3.96 | 0.31 | %TS | 1 | E |
| P2O5 | 0.904 | 0.130 | %TS | 1 | E |
| TiO2 | 1.24 | 0.10 | %TS | 1 | E |
| Sum | 94.3 | | % af TS | 1 | 1 |
| LOI | 3.2 | | % TS | 1 | 1 |
| TS | 96.7 | | % | 1 | V |
| Sb* | 62.5 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






| Deres betegnelse | PSO Kara | Reference sample BA: KARA | | | |
|---|---|---|---|---|---|
| Labnummer | D10085425 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| As | 24.1 | 8.3 | mg/kg TS | 1 | H |
| Ba | 1930 | 143 | mg/kg TS | 1 | E |
| Be | 2.21 | 0.48 | mg/kg TS | 1 | E |
| Cd | 3.09 | 0.56 | mg/kg TS | 1 | H |
| Co | 26.0 | 5.3 | mg/kg TS | 1 | H |
| Cr | 1020 | 136 | mg/kg TS | 1 | E |
| Cu | 8310 | 1190 | mg/kg TS | 1 | E |
| Hg | 0.0400 | 0.0090 | mg/kg TS | 1 | F |
| Mo | 59.4 | 11.2 | mg/kg TS | 1 | E |
| Nb | 9.00 | 6.32 | mg/kg TS | 1 | E |
| Ni | 850 | 120 | mg/kg TS | 1 | E |
| Pb | 1040 | 173 | mg/kg TS | 1 | E |
| S* | 6220 | | mg/kg TS | 1 | A |
| Sc | 2.49 | 1.48 | mg/kg TS | 1 | E |
| Sn* | 167 | | mg/kg TS | 1 | S |
| Sr | 537 | 37 | mg/kg TS | 1 | E |
| V | 109 | 18 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 17.1 | 2.1 | mg/kg TS | 1 | E |
| Zn | 3250 | 471 | mg/kg TS | 1 | E |
| Zr | 342 | 58 | mg/kg TS | 1 | E |
| SiO2 | 48.0 | 3.8 | %TS | 1 | E |
| Al2O3 | 10.4 | 0.9 | %TS | 1 | E |
| CaO | 16.4 | 1.3 | %TS | 1 | E |
| Fe2O3 | 13.6 | 1.1 | %TS | 1 | E |
| K2O | 1.64 | 0.13 | %TS | 1 | E |
| MgO | 2.01 | 0.16 | %TS | 1 | E |
| MnO | 0.174 | 0.017 | %TS | 1 | E |
| Na2O | 2.83 | 0.33 | %TS | 1 | E |
| P2O5 | 0.790 | 0.134 | %TS | 1 | E |
| TiO2 | 1.13 | 0.09 | %TS | 1 | E |
| Sum | 97.0 | | % af TS | 1 | 1 |
| LOI | 2.7 | | % TS | 1 | 1 |
| TS* | 98.3 | | % | 1 | W |
| Sb* | 62.2 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

| Deres betegnelse | PSO Nordfor | Reference sample BA: Nordforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085426 | | | | |
| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
| As | 37.1 | 10.9 | mg/kg TS | 1 | H |
| Ba | 1370 | 101 | mg/kg TS | 1 | E |
| Be | 1.77 | 0.41 | mg/kg TS | 1 | E |
| Cd | 2.53 | 0.49 | mg/kg TS | 1 | H |
| Co | 36.4 | 7.5 | mg/kg TS | 1 | H |
| Cr | 573 | 77 | mg/kg TS | 1 | E |
| Cu | 5380 | 770 | mg/kg TS | 1 | E |
| Hg | <0.01 | | mg/kg TS | 1 | F |
| Mo | <6 | | mg/kg TS | 1 | E |
| Nb | <6 | | mg/kg TS | 1 | E |
| Ni | 250 | 54 | mg/kg TS | 1 | H |
| Pb | 2800 | 467 | mg/kg TS | 1 | E |
| S* | 5130 | | mg/kg TS | 1 | A |
| Sc | <1 | | mg/kg TS | 1 | E |
| Sn* | 252 | | mg/kg TS | 1 | S |
| Sr | 543 | 38 | mg/kg TS | 1 | E |
| V | 51.4 | 9.1 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 10.9 | 1.6 | mg/kg TS | 1 | E |
| Zn | 3810 | 552 | mg/kg TS | 1 | E |
| Zr | 266 | 45 | mg/kg TS | 1 | E |
| SiO2 | 47.5 | 3.8 | %TS | 1 | E |
| Al2O3 | 9.81 | 0.87 | %TS | 1 | E |
| CaO | 15.0 | 1.1 | %TS | 1 | E |
| Fe2O3 | 12.4 | 1.0 | %TS | 1 | E |
| K2O | 1.23 | 0.10 | %TS | 1 | E |
| MgO | 1.83 | 0.14 | %TS | 1 | E |
| MnO | 0.139 | 0.013 | %TS | 1 | E |
| Na2O | 3.88 | 0.31 | %TS | 1 | E |
| P2O5 | 0.808 | 0.116 | %TS | 1 | E |
| TiO2 | 1.16 | 0.09 | %TS | 1 | E |
| Sum | 93.8 | | % af TS | 1 | 1 |
| LOI | 3.0 | | % TS | 1 | 1 |
| TS* | 97.9 | | % | 1 | W |
| Sb* | 95.1 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






| Deres betegnelse | 606A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085437 | | | | |
| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
| As | 20.7 | 7.7 | mg/kg TS | 1 | H |
| Ba | 1570 | 117 | mg/kg TS | 1 | E |
| Be | 1.47 | 0.40 | mg/kg TS | 1 | E |
| Cd | 4.52 | 0.80 | mg/kg TS | 1 | H |
| Co | 16.8 | 3.4 | mg/kg TS | 1 | H |
| Cr | 506 | 68 | mg/kg TS | 1 | E |
| Cu | 7890 | 1140 | mg/kg TS | 1 | E |
| Hg | 0.103 | 0.022 | mg/kg TS | 1 | F |
| Mo | 12.5 | 5.3 | mg/kg TS | 1 | E |
| Nb | 15.4 | 6.7 | mg/kg TS | 1 | E |
| Ni | 198 | 43 | mg/kg TS | 1 | H |
| Pb | 1820 | 304 | mg/kg TS | 1 | E |
| S* | 5520 | | mg/kg TS | 1 | A |
| Sc | 3.79 | 1.47 | mg/kg TS | 1 | E |
| Sn* | 228 | | mg/kg TS | 1 | S |
| Sr | 512 | 36 | mg/kg TS | 1 | E |
| V | 56.2 | 9.9 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 12.2 | 1.7 | mg/kg TS | 1 | E |
| Zn | 4140 | 599 | mg/kg TS | 1 | E |
| Zr | 238 | 40 | mg/kg TS | 1 | E |
| SiO2 | 46.4 | 3.7 | %TS | 1 | E |
| Al2O3 | 9.34 | 0.83 | %TS | 1 | E |
| CaO | 15.3 | 1.2 | %TS | 1 | E |
| Fe2O3 | 11.7 | 0.9 | %TS | 1 | E |
| K2O | 1.17 | 0.10 | %TS | 1 | E |
| MgO | 1.89 | 0.15 | %TS | 1 | E |
| MnO | 0.238 | 0.023 | %TS | 1 | E |
| Na2O | 3.60 | 0.29 | %TS | 1 | E |
| P2O5 | 1.20 | 0.17 | %TS | 1 | E |
| TiO2 | 1.12 | 0.09 | %TS | 1 | E |
| Sum | 92.0 | | % af TS | 1 | 1 |
| LOI | 4.3 | | % TS | 1 | 1 |
| TS* | 98.4 | | % | 1 | W |
| Sb* | 72.8 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

The ALS Laboratory Group

| Deres betegnelse | 609A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085438 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| As | 25.5 | 8.5 | mg/kg TS | 1 | H |
| Ba | 1730 | 129 | mg/kg TS | 1 | E |
| Be | 1.68 | 0.39 | mg/kg TS | 1 | E |
| Cd | 1.94 | 0.37 | mg/kg TS | 1 | H |
| Co | 19.3 | 4.0 | mg/kg TS | 1 | H |
| Cr | 447 | 60 | mg/kg TS | 1 | E |
| Cu | 3190 | 457 | mg/kg TS | 1 | E |
| Hg | 0.0252 | 0.0062 | mg/kg TS | 1 | F |
| Mo | 10.8 | 4.3 | mg/kg TS | 1 | E |
| Nb | 13.0 | 5.8 | mg/kg TS | 1 | E |
| Ni | 181 | 40 | mg/kg TS | 1 | H |
| Pb | 1420 | 237 | mg/kg TS | 1 | E |
| S* | 5260 | | mg/kg TS | 1 | A |
| Sc | 3.16 | 1.38 | mg/kg TS | 1 | E |
| Sn* | 190 | | mg/kg TS | 1 | S |
| Sr | 451 | 31 | mg/kg TS | 1 | E |
| V | 55.8 | 9.6 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 11.7 | 1.6 | mg/kg TS | 1 | E |
| Zn | 3950 | 572 | mg/kg TS | 1 | E |
| Zr | 258 | 44 | mg/kg TS | 1 | E |
| SiO2 | 45.4 | 3.6 | %TS | 1 | E |
| Al2O3 | 9.11 | 0.81 | %TS | 1 | E |
| CaO | 16.0 | 1.2 | %TS | 1 | E |
| Fe2O3 | 13.3 | 1.1 | %TS | 1 | E |
| K2O | 1.09 | 0.09 | %TS | 1 | E |
| MgO | 1.93 | 0.15 | %TS | 1 | E |
| MnO | 0.141 | 0.014 | %TS | 1 | E |
| Na2O | 3.98 | 0.32 | %TS | 1 | E |
| P2O5 | 1.39 | 0.20 | %TS | 1 | E |
| TiO2 | 1.07 | 0.08 | %TS | 1 | E |
| Sum | 93.4 | | % af TS | 1 | 1 |
| LOI | 3.2 | | % TS | 1 | 1 |
| TS* | 98.3 | | % | 1 | W |
| Sb* | 68.4 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






| Deres betegnelse | 611A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085439 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| As | 17.4 | 7.0 | mg/kg TS | 1 | H |
| Ba | 1400 | 104 | mg/kg TS | 1 | E |
| Be | 1.71 | 0.38 | mg/kg TS | 1 | E |
| Cd | 3.17 | 0.58 | mg/kg TS | 1 | H |
| Co | 18.0 | 3.7 | mg/kg TS | 1 | H |
| Cr | 463 | 62 | mg/kg TS | 1 | E |
| Cu | 3580 | 513 | mg/kg TS | 1 | E |
| Hg | 0.0450 | 0.0099 | mg/kg TS | 1 | F |
| Mo | 7.97 | 4.31 | mg/kg TS | 1 | E |
| Nb | 10.4 | 6.0 | mg/kg TS | 1 | E |
| Ni | 170 | 37 | mg/kg TS | 1 | H |
| Pb | 1420 | 237 | mg/kg TS | 1 | E |
| S* | 5400 | | mg/kg TS | 1 | A |
| Sc | 2.93 | 1.47 | mg/kg TS | 1 | E |
| Sn* | 216 | | mg/kg TS | 1 | S |
| Sr | 395 | 27 | mg/kg TS | 1 | E |
| V | 51.3 | 9.1 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 12.7 | 1.8 | mg/kg TS | 1 | E |
| Zn | 3250 | 471 | mg/kg TS | 1 | E |
| Zr | 240 | 41 | mg/kg TS | 1 | E |
| SiO2 | 45.9 | 3.6 | %TS | 1 | E |
| Al2O3 | 9.03 | 0.80 | %TS | 1 | E |
| CaO | 14.7 | 1.1 | %TS | 1 | E |
| Fe2O3 | 13.0 | 1.0 | %TS | 1 | E |
| K2O | 1.17 | 0.10 | %TS | 1 | E |
| MgO | 1.75 | 0.14 | %TS | 1 | E |
| MnO | 0.142 | 0.014 | %TS | 1 | E |
| Na2O | 3.47 | 0.28 | %TS | 1 | E |
| P2O5 | 1.31 | 0.19 | %TS | 1 | E |
| TiO2 | 1.10 | 0.09 | %TS | 1 | E |
| Sum | 91.6 | | % af TS | 1 | 1 |
| LOI | 4.4 | | % TS | 1 | 1 |
| TS* | 98.5 | | % | 1 | W |
| Sb* | 51.8 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

| Deres betegnelse | 612A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085440 | | | | |
| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
| As | 31.6 | 9.6 | mg/kg TS | 1 | H |
| Ba | 1490 | 110 | mg/kg TS | 1 | E |
| Be | 1.66 | 0.38 | mg/kg TS | 1 | E |
| Cd | 2.34 | 0.44 | mg/kg TS | 1 | H |
| Co | 21.3 | 4.3 | mg/kg TS | 1 | H |
| Cr | 470 | 63 | mg/kg TS | 1 | E |
| Cu | 3340 | 479 | mg/kg TS | 1 | E |
| Hg | 0.146 | 0.030 | mg/kg TS | 1 | F |
| Mo | 8.26 | 4.03 | mg/kg TS | 1 | E |
| Nb | 9.44 | 5.66 | mg/kg TS | 1 | E |
| Ni | 225 | 49 | mg/kg TS | 1 | H |
| Pb | 1690 | 282 | mg/kg TS | 1 | E |
| S* | 5210 | | mg/kg TS | 1 | A |
| Sc | 3.21 | 1.38 | mg/kg TS | 1 | E |
| Sn* | 194 | | mg/kg TS | 1 | S |
| Sr | 410 | 29 | mg/kg TS | 1 | E |
| V | 55.3 | 9.6 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 11.9 | 1.7 | mg/kg TS | 1 | E |
| Zn | 4380 | 633 | mg/kg TS | 1 | E |
| Zr | 208 | 35 | mg/kg TS | 1 | E |
| SiO2 | 47.0 | 3.7 | %TS | 1 | E |
| Al2O3 | 8.92 | 0.79 | %TS | 1 | E |
| CaO | 14.9 | 1.1 | %TS | 1 | E |
| Fe2O3 | 13.2 | 1.1 | %TS | 1 | E |
| K2O | 1.13 | 0.09 | %TS | 1 | E |
| MgO | 1.83 | 0.14 | %TS | 1 | E |
| MnO | 0.152 | 0.015 | %TS | 1 | E |
| Na2O | 3.37 | 0.27 | %TS | 1 | E |
| P2O5 | 1.12 | 0.16 | %TS | 1 | E |
| TiO2 | 1.12 | 0.09 | %TS | 1 | E |
| Sum | 92.7 | | % af TS | 1 | 1 |
| LOI | 4.1 | | % TS | 1 | 1 |
| TS* | 98.7 | | % | 1 | W |
| Sb* | 82.4 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






| Deres betegnelse | 613A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085441 | | | | |
| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
| As | 28.3 | 9.1 | mg/kg TS | 1 | H |
| Ba | 1420 | 106 | mg/kg TS | 1 | E |
| Be | 1.41 | 0.41 | mg/kg TS | 1 | E |
| Cd | 2.09 | 0.40 | mg/kg TS | 1 | H |
| Co | 23.0 | 4.7 | mg/kg TS | 1 | H |
| Cr | 697 | 94 | mg/kg TS | 1 | E |
| Cu | 4780 | 684 | mg/kg TS | 1 | E |
| Hg | 0.0297 | 0.0071 | mg/kg TS | 1 | F |
| Mo | 10.7 | 5.1 | mg/kg TS | 1 | E |
| Nb | 9.15 | 7.09 | mg/kg TS | 1 | E |
| Ni | 499 | 71 | mg/kg TS | 1 | E |
| Pb | 2200 | 368 | mg/kg TS | 1 | E |
| S* | 4500 | | mg/kg TS | 1 | A |
| Sc | 2.92 | 1.65 | mg/kg TS | 1 | E |
| Sn* | 200 | | mg/kg TS | 1 | S |
| Sr | 383 | 27 | mg/kg TS | 1 | E |
| V | 50.0 | 9.4 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 10.4 | 1.8 | mg/kg TS | 1 | E |
| Zn | 3360 | 487 | mg/kg TS | 1 | E |
| Zr | 203 | 34 | mg/kg TS | 1 | E |
| SiO2 | 43.3 | 3.4 | %TS | 1 | E |
| Al2O3 | 10.6 | 0.9 | %TS | 1 | E |
| CaO | 14.4 | 1.1 | %TS | 1 | E |
| Fe2O3 | 14.2 | 1.1 | %TS | 1 | E |
| K2O | 1.13 | 0.10 | %TS | 1 | E |
| MgO | 1.81 | 0.14 | %TS | 1 | E |
| MnO | 0.138 | 0.013 | %TS | 1 | E |
| Na2O | 3.61 | 0.29 | %TS | 1 | E |
| P2O5 | 1.78 | 0.26 | %TS | 1 | E |
| TiO2 | 1.04 | 0.08 | %TS | 1 | E |
| Sum | 92.0 | | % af TS | 1 | 1 |
| LOI | 4.1 | | % TS | 1 | 1 |
| TS* | 98.7 | | % | 1 | W |
| Sb* | 74.8 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

| Deres betegnelse | 614A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085442 | | | | |
| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
| As | 33.4 | 10.0 | mg/kg TS | 1 | H |
| Ba | 1290 | 96 | mg/kg TS | 1 | E |
| Be | 1.82 | 0.40 | mg/kg TS | 1 | E |
| Cd | 2.34 | 0.44 | mg/kg TS | 1 | H |
| Co | 24.0 | 4.9 | mg/kg TS | 1 | H |
| Cr | 650 | 87 | mg/kg TS | 1 | E |
| Cu | 2660 | 382 | mg/kg TS | 1 | E |
| Hg | 0.0357 | 0.0082 | mg/kg TS | 1 | F |
| Mo | 11.1 | 4.4 | mg/kg TS | 1 | E |
| Nb | 12.0 | 5.9 | mg/kg TS | 1 | E |
| Ni | 458 | 65 | mg/kg TS | 1 | E |
| Pb | 1070 | 180 | mg/kg TS | 1 | E |
| S* | 4160 | | mg/kg TS | 1 | A |
| Sc | 3.05 | 1.36 | mg/kg TS | 1 | E |
| Sn* | 160 | | mg/kg TS | 1 | S |
| Sr | 369 | 26 | mg/kg TS | 1 | E |
| V | 52.2 | 9.1 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 11.4 | 1.6 | mg/kg TS | 1 | E |
| Zn | 3300 | 479 | mg/kg TS | 1 | E |
| Zr | 232 | 39 | mg/kg TS | 1 | E |
| SiO2 | 44.6 | 3.5 | %TS | 1 | E |
| Al2O3 | 9.59 | 0.85 | %TS | 1 | E |
| CaO | 14.5 | 1.1 | %TS | 1 | E |
| Fe2O3 | 13.0 | 1.0 | %TS | 1 | E |
| K2O | 1.18 | 0.10 | %TS | 1 | E |
| MgO | 1.72 | 0.13 | %TS | 1 | E |
| MnO | 0.139 | 0.013 | %TS | 1 | E |
| Na2O | 3.57 | 0.28 | %TS | 1 | E |
| P2O5 | 1.80 | 0.26 | %TS | 1 | E |
| TiO2 | 1.04 | 0.08 | %TS | 1 | E |
| Sum | 91.1 | | % af TS | 1 | 1 |
| LOI | 4.8 | | % TS | 1 | 1 |
| TS* | 98.5 | | % | 1 | W |
| Sb* | 56.9 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






| Deres betegnelse | 615A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085443 | | | | |
| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
| As | 27.8 | 8.8 | mg/kg TS | 1 | H |
| Ba | 1510 | 112 | mg/kg TS | 1 | E |
| Be | 1.72 | 0.39 | mg/kg TS | 1 | E |
| Cd | 2.07 | 0.39 | mg/kg TS | 1 | H |
| Co | 19.5 | 4.0 | mg/kg TS | 1 | H |
| Cr | 548 | 74 | mg/kg TS | 1 | E |
| Cu | 3590 | 515 | mg/kg TS | 1 | E |
| Hg | 0.228 | 0.047 | mg/kg TS | 1 | F |
| Mo | 12.0 | 4.7 | mg/kg TS | 1 | E |
| Nb | 13.2 | 6.2 | mg/kg TS | 1 | E |
| Ni | 231 | 33 | mg/kg TS | 1 | E |
| Pb | 2570 | 431 | mg/kg TS | 1 | E |
| S* | 4010 | | mg/kg TS | 1 | A |
| Sc | 3.29 | 1.39 | mg/kg TS | 1 | E |
| Sn* | 166 | | mg/kg TS | 1 | S |
| Sr | 349 | 24 | mg/kg TS | 1 | E |
| V | 52.4 | 9.2 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 11.6 | 1.6 | mg/kg TS | 1 | E |
| Zn | 2860 | 416 | mg/kg TS | 1 | E |
| Zr | 214 | 36 | mg/kg TS | 1 | E |
| SiO2 | 45.8 | 3.6 | %TS | 1 | E |
| Al2O3 | 9.60 | 0.86 | %TS | 1 | E |
| CaO | 15.5 | 1.2 | %TS | 1 | E |
| Fe2O3 | 10.2 | 0.8 | %TS | 1 | E |
| K2O | 1.22 | 0.10 | %TS | 1 | E |
| MgO | 1.82 | 0.14 | %TS | 1 | E |
| MnO | 0.113 | 0.011 | %TS | 1 | E |
| Na2O | 3.88 | 0.31 | %TS | 1 | E |
| P2O5 | 2.26 | 0.32 | %TS | 1 | E |
| TiO2 | 0.998 | 0.078 | %TS | 1 | E |
| Sum | 91.4 | | % af TS | 1 | 1 |
| LOI | 4.8 | | % TS | 1 | 1 |
| TS* | 98.9 | | % | 1 | W |
| Sb* | 74.6 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

| Deres betegnelse | 616A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085444 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| As | 25.0 | 8.4 | mg/kg TS | 1 | H |
| Ba | 1540 | 114 | mg/kg TS | 1 | E |
| Be | 1.64 | 0.37 | mg/kg TS | 1 | E |
| Cd | 2.23 | 0.41 | mg/kg TS | 1 | H |
| Co | 23.3 | 4.8 | mg/kg TS | 1 | H |
| Cr | 539 | 72 | mg/kg TS | 1 | E |
| Cu | 3070 | 440 | mg/kg TS | 1 | E |
| Hg | <0.01 | | mg/kg TS | 1 | F |
| Mo | 9.33 | 4.15 | mg/kg TS | 1 | E |
| Nb | 11.4 | 5.8 | mg/kg TS | 1 | E |
| Ni | 324 | 46 | mg/kg TS | 1 | E |
| Pb | 645 | 114 | mg/kg TS | 1 | H |
| S* | 4030 | | mg/kg TS | 1 | A |
| Sc | 2.72 | 1.36 | mg/kg TS | 1 | E |
| Sn* | 222 | | mg/kg TS | 1 | S |
| Sr | 322 | 22 | mg/kg TS | 1 | E |
| V | 47.8 | 8.5 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 9.36 | 1.48 | mg/kg TS | 1 | E |
| Zn | 3360 | 487 | mg/kg TS | 1 | E |
| Zr | 246 | 42 | mg/kg TS | 1 | E |
| SiO2 | 43.8 | 3.5 | %TS | 1 | E |
| Al2O3 | 10.8 | 1.0 | %TS | 1 | E |
| CaO | 15.4 | 1.2 | %TS | 1 | E |
| Fe2O3 | 12.5 | 1.0 | %TS | 1 | E |
| K2O | 1.21 | 0.10 | %TS | 1 | E |
| MgO | 1.73 | 0.14 | %TS | 1 | E |
| MnO | 0.138 | 0.013 | %TS | 1 | E |
| Na2O | 4.02 | 0.32 | %TS | 1 | E |
| P2O5 | 2.62 | 0.38 | %TS | 1 | E |
| TiO2 | 1.06 | 0.08 | %TS | 1 | E |
| Sum | 93.3 | | % af TS | 1 | 1 |
| LOI | 3.6 | | % TS | 1 | 1 |
| TS* | 98.8 | | % | 1 | W |
| Sb* | 67.1 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






| Deres betegnelse | 617A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085445 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| As | 25.3 | 8.3 | mg/kg TS | 1 | H |
| Ba | 1490 | 111 | mg/kg TS | 1 | E |
| Be | 1.74 | 0.39 | mg/kg TS | 1 | E |
| Cd | 2.44 | 0.46 | mg/kg TS | 1 | H |
| Co | 19.9 | 4.2 | mg/kg TS | 1 | H |
| Cr | 434 | 58 | mg/kg TS | 1 | E |
| Cu | 3180 | 456 | mg/kg TS | 1 | E |
| Hg | 0.0473 | 0.0103 | mg/kg TS | 1 | F |
| Mo | <6 | | mg/kg TS | 1 | E |
| Nb | <6 | | mg/kg TS | 1 | E |
| Ni | 232 | 33 | mg/kg TS | 1 | E |
| Pb | 1210 | 203 | mg/kg TS | 1 | E |
| S* | 4510 | | mg/kg TS | 1 | A |
| Sc | 1.42 | 1.39 | mg/kg TS | 1 | E |
| Sn* | 237 | | mg/kg TS | 1 | S |
| Sr | 461 | 32 | mg/kg TS | 1 | E |
| V | 43.5 | 8.1 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 11.2 | 1.6 | mg/kg TS | 1 | E |
| Zn | 3100 | 449 | mg/kg TS | 1 | E |
| Zr | 236 | 40 | mg/kg TS | 1 | E |
| SiO2 | 44.2 | 3.5 | %TS | 1 | E |
| Al2O3 | 9.47 | 0.84 | %TS | 1 | E |
| CaO | 15.4 | 1.2 | %TS | 1 | E |
| Fe2O3 | 12.0 | 1.0 | %TS | 1 | E |
| K2O | 1.15 | 0.09 | %TS | 1 | E |
| MgO | 1.80 | 0.14 | %TS | 1 | E |
| MnO | 0.131 | 0.013 | %TS | 1 | E |
| Na2O | 3.77 | 0.30 | %TS | 1 | E |
| P2O5 | 2.30 | 0.33 | %TS | 1 | E |
| TiO2 | 0.983 | 0.077 | %TS | 1 | E |
| Sum | 91.2 | | % af TS | 1 | 1 |
| LOI | 4.9 | | % TS | 1 | 1 |
| TS* | 98.4 | | % | 1 | W |
| Sb* | 89.9 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

| Deres betegnelse | 701A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085446 | | | | |
| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
| As | 27.8 | 8.9 | mg/kg TS | 1 | H |
| Ba | 1240 | 92 | mg/kg TS | 1 | E |
| Be | 1.93 | 0.41 | mg/kg TS | 1 | E |
| Cd | 3.11 | 0.56 | mg/kg TS | 1 | H |
| Co | 17.3 | 3.7 | mg/kg TS | 1 | H |
| Cr | 467 | 63 | mg/kg TS | 1 | E |
| Cu | 2750 | 394 | mg/kg TS | 1 | E |
| Hg | 0.137 | 0.029 | mg/kg TS | 1 | F |
| Mo | 10.7 | 4.3 | mg/kg TS | 1 | E |
| Nb | 10.8 | 5.8 | mg/kg TS | 1 | E |
| Ni | 235 | 51 | mg/kg TS | 1 | H |
| Pb | 1200 | 202 | mg/kg TS | 1 | E |
| S* | 3950 | | mg/kg TS | 1 | A |
| Sc | 3.08 | 1.40 | mg/kg TS | 1 | E |
| Sn* | 205 | | mg/kg TS | 1 | S |
| Sr | 325 | 23 | mg/kg TS | 1 | E |
| V | 45.2 | 8.2 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 11.5 | 1.6 | mg/kg TS | 1 | E |
| Zn | 4360 | 631 | mg/kg TS | 1 | E |
| Zr | 198 | 33 | mg/kg TS | 1 | E |
| SiO2 | 44.1 | 3.5 | %TS | 1 | E |
| Al2O3 | 9.09 | 0.81 | %TS | 1 | E |
| CaO | 14.7 | 1.1 | %TS | 1 | E |
| Fe2O3 | 11.7 | 0.9 | %TS | 1 | E |
| K2O | 1.17 | 0.10 | %TS | 1 | E |
| MgO | 1.69 | 0.13 | %TS | 1 | E |
| MnO | 0.216 | 0.021 | %TS | 1 | E |
| Na2O | 4.15 | 0.33 | %TS | 1 | E |
| P2O5 | 2.35 | 0.34 | %TS | 1 | E |
| TiO2 | 0.947 | 0.074 | %TS | 1 | E |
| Sum | 90.1 | | % af TS | 1 | 1 |
| LOI | 5.8 | | % TS | 1 | 1 |
| TS* | 98.2 | | % | 1 | W |
| Sb* | 51.7 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






| Deres betegnelse | 702A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085447 | | | | |
| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
| As | 21.6 | 7.7 | mg/kg TS | 1 | H |
| Ba | 1340 | 99 | mg/kg TS | 1 | E |
| Be | 1.52 | 0.39 | mg/kg TS | 1 | E |
| Cd | 2.09 | 0.39 | mg/kg TS | 1 | H |
| Co | 18.8 | 3.8 | mg/kg TS | 1 | H |
| Cr | 909 | 122 | mg/kg TS | 1 | E |
| Cu | 2970 | 426 | mg/kg TS | 1 | E |
| Hg | 0.0302 | 0.0071 | mg/kg TS | 1 | F |
| Mo | <6 | | mg/kg TS | 1 | E |
| Nb | <6 | | mg/kg TS | 1 | E |
| Ni | 355 | 50 | mg/kg TS | 1 | E |
| Pb | 1240 | 208 | mg/kg TS | 1 | E |
| S* | 4180 | | mg/kg TS | 1 | A |
| Sc | 1.33 | 1.44 | mg/kg TS | 1 | E |
| Sn* | 230 | | mg/kg TS | 1 | S |
| Sr | 439 | 31 | mg/kg TS | 1 | E |
| V | 43.1 | 8.0 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 10.3 | 1.6 | mg/kg TS | 1 | E |
| Zn | 3610 | 523 | mg/kg TS | 1 | E |
| Zr | 230 | 39 | mg/kg TS | 1 | E |
| SiO2 | 44.0 | 3.5 | %TS | 1 | E |
| Al2O3 | 9.22 | 0.82 | %TS | 1 | E |
| CaO | 15.4 | 1.2 | %TS | 1 | E |
| Fe2O3 | 12.6 | 1.0 | %TS | 1 | E |
| K2O | 1.13 | 0.09 | %TS | 1 | E |
| MgO | 1.80 | 0.14 | %TS | 1 | E |
| MnO | 0.130 | 0.012 | %TS | 1 | E |
| Na2O | 3.84 | 0.31 | %TS | 1 | E |
| P2O5 | 2.27 | 0.33 | %TS | 1 | E |
| TiO2 | 1.02 | 0.08 | %TS | 1 | E |
| Sum | 91.4 | | % af TS | 1 | 1 |
| LOI | 4.3 | | % TS | 1 | 1 |
| TS* | 98.5 | | % | 1 | W |
| Sb* | 61.6 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

| Deres betegnelse | 703A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085448 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| As | 37.0 | 10.7 | mg/kg TS | 1 | H |
| Ba | 1290 | 96 | mg/kg TS | 1 | E |
| Be | 1.50 | 0.37 | mg/kg TS | 1 | E |
| Cd | 1.96 | 0.37 | mg/kg TS | 1 | H |
| Co | 19.6 | 4.0 | mg/kg TS | 1 | H |
| Cr | 430 | 58 | mg/kg TS | 1 | E |
| Cu | 2740 | 392 | mg/kg TS | 1 | E |
| Hg | 0.0914 | 0.0193 | mg/kg TS | 1 | F |
| Mo | 10.9 | 4.5 | mg/kg TS | 1 | E |
| Nb | 13.3 | 5.8 | mg/kg TS | 1 | E |
| Ni | 164 | 36 | mg/kg TS | 1 | H |
| Pb | 1680 | 281 | mg/kg TS | 1 | E |
| S* | 5680 | | mg/kg TS | 1 | A |
| Sc | 2.24 | 1.33 | mg/kg TS | 1 | E |
| Sn* | 328 | | mg/kg TS | 1 | S |
| Sr | 373 | 26 | mg/kg TS | 1 | E |
| V | 48.2 | 8.5 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 10.9 | 1.6 | mg/kg TS | 1 | E |
| Zn | 3520 | 510 | mg/kg TS | 1 | E |
| Zr | 359 | 61 | mg/kg TS | 1 | E |
| SiO2 | 43.8 | 3.5 | %TS | 1 | E |
| Al2O3 | 10.3 | 0.9 | %TS | 1 | E |
| CaO | 16.0 | 1.2 | %TS | 1 | E |
| Fe2O3 | 11.7 | 0.9 | %TS | 1 | E |
| K2O | 1.14 | 0.09 | %TS | 1 | E |
| MgO | 1.86 | 0.15 | %TS | 1 | E |
| MnO | 0.179 | 0.017 | %TS | 1 | E |
| Na2O | 3.83 | 0.30 | %TS | 1 | E |
| P2O5 | 2.27 | 0.33 | %TS | 1 | E |
| TiO2 | 1.09 | 0.09 | %TS | 1 | E |
| Sum | 92.2 | | % af TS | 1 | 1 |
| LOI | 4.2 | | % TS | 1 | 1 |
| TS* | 98.2 | | % | 1 | W |
| Sb* | 69.7 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






| Deres betegnelse | 706A | BA Time series: Amagerforbrænding | | | |
|---|---|---|---|---|---|
| Labnummer | D10085449 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| As | 33.8 | 10.2 | mg/kg TS | 1 | H |
| Ba | 1240 | 92 | mg/kg TS | 1 | E |
| Be | 1.30 | 0.33 | mg/kg TS | 1 | E |
| Cd | 3.12 | 0.58 | mg/kg TS | 1 | H |
| Co | 1230 | 179 | mg/kg TS | 1 | E |
| Cr | 464 | 62 | mg/kg TS | 1 | E |
| Cu | 5560 | 811 | mg/kg TS | 1 | E |
| Hg | 0.0397 | 0.0089 | mg/kg TS | 1 | F |
| Mo | <6 | | mg/kg TS | 1 | E |
| Nb | <6 | | mg/kg TS | 1 | E |
| Ni | 240 | 52 | mg/kg TS | 1 | H |
| Pb | 1270 | 211 | mg/kg TS | 1 | E |
| S* | 5650 | | mg/kg TS | 1 | A |
| Sc | <1 | | mg/kg TS | 1 | E |
| Sn* | 209 | | mg/kg TS | 1 | S |
| Sr | 435 | 30 | mg/kg TS | 1 | E |
| V | 42.8 | 7.9 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 10.3 | 1.6 | mg/kg TS | 1 | E |
| Zn | 3430 | 496 | mg/kg TS | 1 | E |
| Zr | 256 | 43 | mg/kg TS | 1 | E |
| SiO2 | 46.3 | 3.7 | %TS | 1 | E |
| Al2O3 | 9.46 | 0.84 | %TS | 1 | E |
| CaO | 14.7 | 1.1 | %TS | 1 | E |
| Fe2O3 | 11.4 | 0.9 | %TS | 1 | E |
| K2O | 1.14 | 0.09 | %TS | 1 | E |
| MgO | 1.78 | 0.14 | %TS | 1 | E |
| MnO | 0.173 | 0.017 | %TS | 1 | E |
| Na2O | 3.94 | 0.31 | %TS | 1 | E |
| P2O5 | 1.20 | 0.17 | %TS | 1 | E |
| TiO2 | 0.985 | 0.077 | %TS | 1 | E |
| Sum | 91.1 | | % af TS | 1 | 1 |
| LOI | 5.2 | | % TS | 1 | 1 |
| TS* | 97.1 | | % | 1 | W |
| Sb* | 73.9 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

Deres betegnelse **707A**

BA Time series: Amagerforbrænding

Labnummer D10085450

| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
|---|---|---|---|---|---|
| As | 23.0 | 8.1 | mg/kg TS | 1 | H |
| Ba | 1420 | 106 | mg/kg TS | 1 | E |
| Be | 1.23 | 0.55 | mg/kg TS | 1 | E |
| Cd | 2.60 | 0.50 | mg/kg TS | 1 | H |
| Co | 22.5 | 4.6 | mg/kg TS | 1 | H |
| Cr | 573 | 78 | mg/kg TS | 1 | E |
| Cu | 2630 | 377 | mg/kg TS | 1 | E |
| Hg | 0.0843 | 0.0178 | mg/kg TS | 1 | F |
| Mo | 12.9 | 6.7 | mg/kg TS | 1 | E |
| Nb | 12.1 | 8.2 | mg/kg TS | 1 | E |
| Ni | 247 | 54 | mg/kg TS | 1 | H |
| Pb | 982 | 164 | mg/kg TS | 1 | E |
| S* | 6200 | | mg/kg TS | 1 | A |
| Sc | 1.71 | 1.83 | mg/kg TS | 1 | E |
| Sn* | 192 | | mg/kg TS | 1 | S |
| Sr | 367 | 26 | mg/kg TS | 1 | E |
| V | 51.3 | 9.7 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 11.5 | 1.6 | mg/kg TS | 1 | E |
| Zn | 3940 | 570 | mg/kg TS | 1 | E |
| Zr | 291 | 49 | mg/kg TS | 1 | E |
| SiO2 | 43.4 | 3.4 | %TS | 1 | E |
| Al2O3 | 9.61 | 0.86 | %TS | 1 | E |
| CaO | 16.2 | 1.2 | %TS | 1 | E |
| Fe2O3 | 12.8 | 1.0 | %TS | 1 | E |
| K2O | 1.07 | 0.09 | %TS | 1 | E |
| MgO | 1.77 | 0.14 | %TS | 1 | E |
| MnO | 0.184 | 0.018 | %TS | 1 | E |
| Na2O | 3.95 | 0.32 | %TS | 1 | E |
| P2O5 | 1.89 | 0.27 | %TS | 1 | E |
| TiO2 | 1.04 | 0.08 | %TS | 1 | E |
| Sum | 91.9 | | % af TS | 1 | 1 |
| LOI | 4.9 | | % TS | 1 | 1 |
| TS* | 97.9 | | % | 1 | W |
| Sb* | 67.9 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






Deres betegnelse **Aarhus 94a**

BA Time series: Århus

Labnummer D10085451

| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
|---|---|---|---|---|---|
| As | 31.1 | 9.4 | mg/kg TS | 1 | H |
| Ba | 2030 | 151 | mg/kg TS | 1 | E |
| Be | 1.89 | 0.48 | mg/kg TS | 1 | E |
| Cd | 4.66 | 0.83 | mg/kg TS | 1 | H |
| Co | 33.9 | 6.9 | mg/kg TS | 1 | H |
| Cr | 537 | 73 | mg/kg TS | 1 | E |
| Cu | 8110 | 1160 | mg/kg TS | 1 | E |
| Hg | 0.0111 | 0.0040 | mg/kg TS | 1 | F |
| Mo | 11.0 | 5.9 | mg/kg TS | 1 | E |
| Nb | 6.10 | 7.32 | mg/kg TS | 1 | E |
| Ni | 303 | 43 | mg/kg TS | 1 | E |
| Pb | 1620 | 271 | mg/kg TS | 1 | E |
| S* | 3800 | | mg/kg TS | 1 | A |
| Sc | <1 | | mg/kg TS | 1 | E |
| Sn* | 396 | | mg/kg TS | 1 | S |
| Sr | 415 | 29 | mg/kg TS | 1 | E |
| V | 55.8 | 10.1 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 11.6 | 1.7 | mg/kg TS | 1 | E |
| Zn | 4250 | 616 | mg/kg TS | 1 | E |
| Zr | 326 | 55 | mg/kg TS | 1 | E |
| SiO2 | 44.3 | 3.5 | %TS | 1 | E |
| Al2O3 | 9.92 | 0.88 | %TS | 1 | E |
| CaO | 14.8 | 1.1 | %TS | 1 | E |
| Fe2O3 | 14.2 | 1.1 | %TS | 1 | E |
| K2O | 0.933 | 0.080 | %TS | 1 | E |
| MgO | 1.90 | 0.15 | %TS | 1 | E |
| MnO | 0.212 | 0.020 | %TS | 1 | E |
| Na2O | 3.87 | 0.31 | %TS | 1 | E |
| P2O5 | 0.862 | 0.124 | %TS | 1 | E |
| TiO2 | 1.21 | 0.10 | %TS | 1 | E |
| Sum | 92.2 | | % af TS | 1 | 1 |
| LOI | 4.5 | | % TS | 1 | 1 |
| TS* | 98.9 | | % | 1 | W |
| Sb* | 87.2 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

Deres betegnelse **Aarhus 91a**

BA Time series: Århus

Labnummer D10085452

| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
|---|---|---|---|---|---|
| As | 41.4 | 11.8 | mg/kg TS | 1 | H |
| Ba | 1880 | 139 | mg/kg TS | 1 | E |
| Be | 1.53 | 0.38 | mg/kg TS | 1 | E |
| Cd | 2.11 | 0.40 | mg/kg TS | 1 | H |
| Co | 21.6 | 4.4 | mg/kg TS | 1 | H |
| Cr | 571 | 77 | mg/kg TS | 1 | E |
| Cu | 2590 | 372 | mg/kg TS | 1 | E |
| Hg | 0.0543 | 0.0118 | mg/kg TS | 1 | F |
| Mo | 12.2 | 4.7 | mg/kg TS | 1 | E |
| Nb | 9.09 | 5.82 | mg/kg TS | 1 | E |
| Ni | 171 | 24 | mg/kg TS | 1 | E |
| Pb | 1350 | 226 | mg/kg TS | 1 | E |
| S* | 5180 | | mg/kg TS | 1 | A |
| Sc | 1.55 | 1.36 | mg/kg TS | 1 | E |
| Sn* | 207 | | mg/kg TS | 1 | S |
| Sr | 362 | 25 | mg/kg TS | 1 | E |
| V | 62.1 | 10.5 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 13.1 | 1.7 | mg/kg TS | 1 | E |
| Zn | 3390 | 491 | mg/kg TS | 1 | E |
| Zr | 222 | 38 | mg/kg TS | 1 | E |
| SiO2 | 46.7 | 3.7 | %TS | 1 | E |
| Al2O3 | 10.7 | 1.0 | %TS | 1 | E |
| CaO | 14.8 | 1.1 | %TS | 1 | E |
| Fe2O3 | 12.3 | 1.0 | %TS | 1 | E |
| K2O | 1.07 | 0.09 | %TS | 1 | E |
| MgO | 1.85 | 0.15 | %TS | 1 | E |
| MnO | 0.144 | 0.014 | %TS | 1 | E |
| Na2O | 3.30 | 0.26 | %TS | 1 | E |
| P2O5 | 0.889 | 0.128 | %TS | 1 | E |
| TiO2 | 1.41 | 0.11 | %TS | 1 | E |
| Sum | 93.2 | | % af TS | 1 | 1 |
| LOI | 4.1 | | % TS | 1 | 1 |
| TS* | 97.3 | | % | 1 | W |
| Sb* | 80.5 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






Deres betegnelse **Aarhus 71a**

BA Time series: Århus

Labnummer D10085453

| Parameter | Resultat | Måleusikkerhed (±) | Enhed | Metode | Teknik/Udf. Enhed |
|---|---|---|---|---|---|
| As | 31.7 | 9.7 | mg/kg TS | 1 | H |
| Ba | 1370 | 102 | mg/kg TS | 1 | E |
| Be | 1.52 | 0.37 | mg/kg TS | 1 | E |
| Cd | 3.29 | 0.58 | mg/kg TS | 1 | H |
| Co | 21.6 | 4.4 | mg/kg TS | 1 | H |
| Cr | 513 | 69 | mg/kg TS | 1 | E |
| Cu | 7150 | 1070 | mg/kg TS | 1 | E |
| Hg | 0.0727 | 0.0154 | mg/kg TS | 1 | F |
| Mo | <6 | | mg/kg TS | 1 | E |
| Nb | <6 | | mg/kg TS | 1 | E |
| Ni | 420 | 91 | mg/kg TS | 1 | H |
| Pb | 835 | 140 | mg/kg TS | 1 | E |
| S* | 3550 | | mg/kg TS | 1 | A |
| Sc | <1 | | mg/kg TS | 1 | E |
| Sn* | 220 | | mg/kg TS | 1 | S |
| Sr | 345 | 24 | mg/kg TS | 1 | E |
| V | 50.4 | 9.2 | mg/kg TS | 1 | E |
| W | <60 | | mg/kg TS | 1 | E |
| Y | 13.4 | 1.8 | mg/kg TS | 1 | E |
| Zn | 2820 | 411 | mg/kg TS | 1 | E |
| Zr | 275 | 47 | mg/kg TS | 1 | E |
| SiO2 | 48.8 | 3.9 | %TS | 1 | E |
| Al2O3 | 10.0 | 0.9 | %TS | 1 | E |
| CaO | 13.5 | 1.0 | %TS | 1 | E |
| Fe2O3 | 11.7 | 0.9 | %TS | 1 | E |
| K2O | 1.09 | 0.09 | %TS | 1 | E |
| MgO | 1.83 | 0.14 | %TS | 1 | E |
| MnO | 0.160 | 0.015 | %TS | 1 | E |
| Na2O | 3.71 | 0.30 | %TS | 1 | E |
| P2O5 | 0.876 | 0.126 | %TS | 1 | E |
| TiO2 | 1.11 | 0.09 | %TS | 1 | E |
| Sum | 92.8 | | % af TS | 1 | 1 |
| LOI | 3.9 | | % TS | 1 | 1 |
| TS* | 98.7 | | % | 1 | W |
| Sb* | 88.6 | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

| | | | | | |
|---|---|---|---|---|---|
| Deres betegnelse | **Aarhus 89a** | | | | BA Time series: Århus |
| Labnummer | D10085454 | | | | |
| **Parameter** | **Resultat** | **Måleusikkerhed (±)** | **Enhed** | **Metode** | **Teknik/Udf. Enhed** |
| **As** | **81.9** | 21.2 | mg/kg TS | 1 | H |
| **Ba** | **2290** | 171 | mg/kg TS | 1 | E |
| **Be** | **1.69** | 0.54 | mg/kg TS | 1 | E |
| **Cd** | **1.86** | 0.35 | mg/kg TS | 1 | H |
| **Co** | **20.4** | 4.2 | mg/kg TS | 1 | H |
| **Cr** | **630** | 86 | mg/kg TS | 1 | E |
| **Cu** | **2550** | 366 | mg/kg TS | 1 | E |
| **Hg** | **0.0113** | 0.0041 | mg/kg TS | 1 | F |
| **Mo** | **22.3** | 7.3 | mg/kg TS | 1 | E |
| **Nb** | **14.6** | 7.7 | mg/kg TS | 1 | E |
| **Ni** | **377** | 82 | mg/kg TS | 1 | H |
| **Pb** | **1070** | 179 | mg/kg TS | 1 | E |
| **S*** | **5530** | | mg/kg TS | 1 | A |
| **Sc** | **2.31** | 1.52 | mg/kg TS | 1 | E |
| **Sn*** | **292** | | mg/kg TS | 1 | S |
| **Sr** | **431** | 30 | mg/kg TS | 1 | E |
| **V** | **71.2** | 12.3 | mg/kg TS | 1 | E |
| **W** | **<60** | | mg/kg TS | 1 | E |
| **Y** | **14.8** | 1.9 | mg/kg TS | 1 | E |
| **Zn** | **3110** | 451 | mg/kg TS | 1 | E |
| **Zr** | **236** | 40 | mg/kg TS | 1 | E |
| **SiO2** | **44.9** | 3.6 | %TS | 1 | E |
| **Al2O3** | **9.89** | 0.88 | %TS | 1 | E |
| **CaO** | **16.1** | 1.2 | %TS | 1 | E |
| **Fe2O3** | **12.8** | 1.0 | %TS | 1 | E |
| **K2O** | **1.02** | 0.09 | %TS | 1 | E |
| **MgO** | **2.07** | 0.16 | %TS | 1 | E |
| **MnO** | **0.198** | 0.019 | %TS | 1 | E |
| **Na2O** | **3.71** | 0.30 | %TS | 1 | E |
| **P2O5** | **0.870** | 0.126 | %TS | 1 | E |
| **TiO2** | **1.31** | 0.10 | %TS | 1 | E |
| **Sum** | **92.9** | | % af TS | 1 | 1 |
| **LOI** | **3.9** | | % TS | 1 | 1 |
| **TS*** | **96.7** | | % | 1 | W |
| **Sb*** | **85.0** | | mg/kg TS | 1 | S |


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant






* efter parameternavn indikerer ikke akkrediteret analyse.

| | Metode |
|---|---|
| 1 | Bestemmelse af sporstoffer samt oxider inkl. oplukning.<br>Oplukning: For bestemmelse af As, Cd, Co, Cu, Hg, Ni, Pb, S og Zn tørres prøven ved 50°C og opløses i saltpetersyre/hydrogenperoxid i lukkede teflonbeholdere i mikroovn. (indeholdt korrigeres til TS 105°C.) Øvrige emner bestemmes efter smelte med lithiummetaborat efterfulgt af opløsning i fortyndet saltpetesyre.<br><br>Analysen er gennemført iht. EPA metoder 200.7 (ICP-AES) og 200.8 (ICP-QMS/SFMS). |

| | Teknik / Udførende enhed[1] |
|---|---|
| A | Måling udføres med ICP-AES<br>Akk. Lab Reg.nr. 1087. |
| E | Måling udføres med ICP-AES<br>Akk. Lab Reg.nr. 1087. |
| F | Måling udføres med AFS<br>Akk. Lab. Reg.nr. 1087. |
| H | Måling udføres med ICP-SFMS<br>Akk. Lab. Reg.nr. 1087. |
| S | Måling udføres med ICP-SFMS<br>Akk. Lab. Reg.nr. 1087. |
| V | Våtkemi |
| W | Vådkemi |
| 1 | Akk. Lab. Reg.nr. 1087 |

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Måleusikkerheden angives som en udvidet usikkerhed (iht. Definitionen i "Guide to the Expression of uncertainty in Measurement", ISO, Geneva, Switzerland 1993) beregnet med en dækningsfaktor lig med 2 hvilket giver et konfidensniveau på ca. 95%.

Denne rapport må kun gengives i uddrag, hvis den enten er offentlig tilgængelig, eller hvis laboratoriet har godkendt uddraget. Resultaterne gælder kun denne prøve.

For gældende ansvar, se aktuelt produktkatalog eller vores hjemmeside www.alsglobal.dk

ALS Scanavias laboratorier er akkrediteret af SWEDAC for et flertal analysemetoder (reg.nr. 1087). Det indebær at den internationale standard i DS-EN ISO/IEC 17025 opfyldes. For visse analyser anvender ALS Scandinavia akkrediterede europæiske underleverandører. Deres akkrediteringer accepteres af SWEDAC og DANAK som ligeværdige med egne akkrediteringer iht. aftale inden for det internationale samarbejdsorgan EA (European Accreditations).

[1] ALS Laboratorium eller underleverandør.


ALS Scandinavia AB
Jagtvej 115 E
DK-2200 København N
Denmark

Webb: www.alsglobal.dk
E-post: info.cp@alsglobal.com
Tel: + 45 3585 6400
Fax: + 45 3581 5583

Kirsten Drackenberg
Laborant

# Appendix VIII

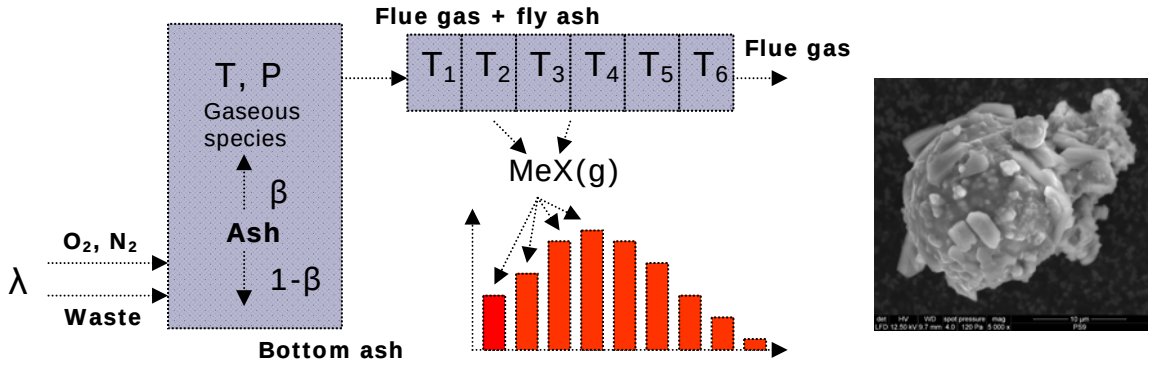
Modeling of heterogeneous condensation

# Modeling of heterogeneous condensation

**Model approach**

*Task:* A physical model for heterogeneous condensation on a size distributed fly ash is developed and coupled with an existing equilibrium model.

*Approach:* A two-compartment system (as described by Sørum et al., 2003): (1) Release from the grate: Vaporization of elements. (2) Condensation of elements in the flue gas channel as a function of T. The idea is sketched in Figure 1.




The model is one-dimensional in time and consists of (1) specifying the initial conditions in the system (2) computing the target element condensation as a function of T.

Gas/solid equilibrium is calculated at each step using the commercial equilibrium model FactSage™ (version 5.2), and interactions between vapor phase and particle surface are calculated by fluxes, with units of moles per second per particle.

While most other modeling studies have considered uniform sized spherical particles and coal fly ash, our study consider size distributed, non-spherical, waste incineration fly ash.

A flow chart of our model is outlined in Figure 2. The model is inspired by a physical model derived by Senior et al. (2006), considering arsenic partitioning in coal-fired power plants.

Assumptions, limitations and uncertainties are addressed and discussed below (with references to relevant literature).

**Model assumptions and limitations**

Heterogeneous condensation is defined as condensation on the surface of existing particles.

In the present model heterogeneous condensation is assumed to be the only mechanism by which particulate matter becomes enriched with heavy metals. Surface reactions are not included, neither are homogeneous condensation of trace metals (formation of new aerosol particles by nucleation).

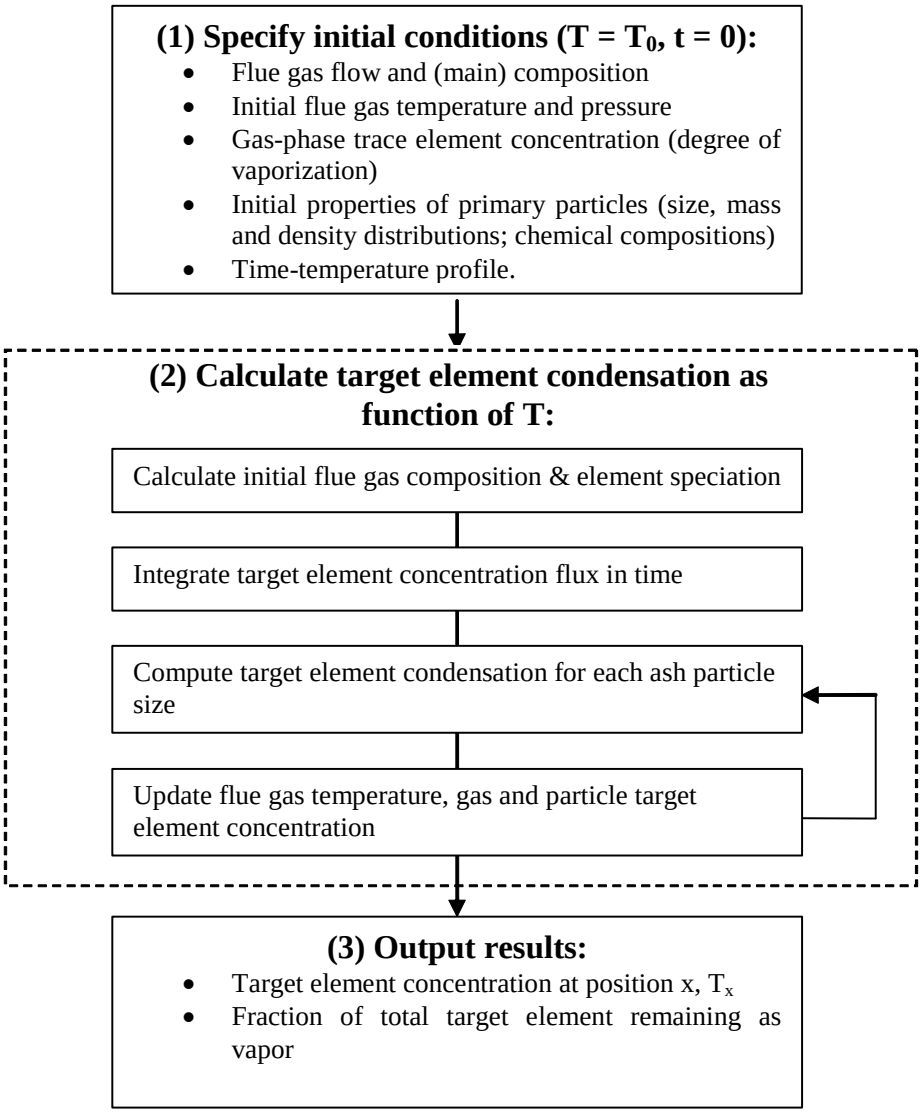



*Figure 2. Flow chart for modeling of heterogeneous condensation on a size distributed fly ash. Target element: Pb, Zn, Cu, Cd etc.*

*Particle growth:*
The net source of particles of size v, at position x, and time t [$1/m^3s$], can be described by *the particle growth equation* (a) (Linak & Wendt, 1994):

$$R_v = R_{nucl} + R_{coag} + R_{cond} \qquad \text{(nucleation + coagulation + condensation)} \qquad (a)$$

The volatile trace metals condense only in the cooler zones of the furnace, therefore nucleation and coagulation can be ignored.

*Vapor phase – particle surface interactions. The condensation flux equation:*
Interactions between vapor phase and particle surface are calculated by fluxes. The mechanisms depend on the gas-phase transport regime: free molecular (submicrometer) or continuum (supermicrometer).

The condensation flux equation, $R_{cond}$, [mol/m$^3$·s], on uniform sized spherical particles of diameter $d_p$ [m] in the continuum (supermicrometer) regime is diffusion limited and given by equation (b) (Frandsen, 1995; Neville & Sarofim, 1985, Senior et al., 2006). To solve for a size distributed fly ash, the particle size distribution is discriminated and the equation is solved for each size fraction.

$$R_{cond} = F_i(d_p) = \frac{2 \cdot \pi \cdot d_p \cdot D_{Xm}}{R \cdot T} \cdot P_{LOAD} \cdot (p_\infty - p_s) \cdot \left[ \frac{1 + Kn}{1 + 1.71 \cdot Kn + 1.333 \cdot (Kn)^2} \right] \quad \text{(b)}$$

where $D_{Xm}$ is the molecular diffusivity of X in a multicomponent gas, m, $p_\infty$ and $p_s$ is the bulk and surface pressure of X, $P_{LOAD}$ [1/m$^3$] is the particle loading of the gas, and Kn = $2\lambda/d_i$ is the Knudsen number. The mean free path, $\lambda$ (computed by (c)) is ~0.5 μm for combustion gases (Senior et al., 2006; Neville & Sarofim, 1985):

$$\lambda = \frac{\mu}{\rho}\left(\frac{\pi MW}{2RT}\right)^{1/2} \quad \text{(c)}$$

where the molecular weight, viscosity, and density of the gas are calculated using the overall gas composition

The term in the brackets in equation (b) is the Fuchs-Sutugin correction for the non-continuum behavior of small particles. $D_{Xm}$ can be estimated for any molecular component X in m using *an empiric equation* (d) of Fuller, Schettler and Giddings (Fuller et al., 1969). The empirical equation of Fuller, Schettler, and Giddings utilizes empirical constants derived from experimental data:

$$D_{AB} = D_{BA} = \frac{0.00143T^{1.75}}{PM_{AB}^{1/2}\left[(\sum_V)_A^{1/3} + (\sum_V)_B^{1/3}\right]^2}, \quad \text{(d)}$$

Where $D_{AB}$ is in cm$^2$/s, P is in atm, T is in K. M are the molecular weights (g/mol). V are the atomic diffusion volumes.

The condensation flux in the free molecular regime (submicrometer particles) is given by (e) (Senior et al., 2006; Neville & Sarofim, 1985):

$$R_{cond} = \frac{\psi \pi d_p^2 (p_\infty - p_S)}{(2\pi MWRT)^{1/2}} \cdot P_{LOAD} \qquad \text{, MW = molecular weight (g/mol)} \qquad \text{(e)}$$

where Ψ (psi) is the accommodation coefficient, or the fraction of successful collision with the particle surface, taken as unity (if spherical particles. Corrections (> 1) must be made for non-spherical particles).

For the submicrometer particles an allowance must be made for the Kelvin effect (increase in equilibrium pressure with decrease in droplet diameter) (Neville & Sarofim, 1985).

*Condensation vs. particle size:*
A simple geometric model for volume percentage of condensed surface layer on a spherical fly ash particle is outlined on Figure 3 (Nutalapati et al., 2007).

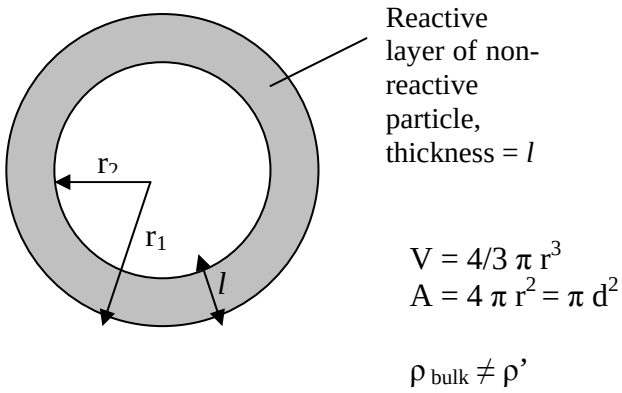



*Figure3: Geometric model for volume percentage of condensed surface layer on a spherical fly ash particle*

The thickness of the condensed surface layer is in the nm range (0.01 – 50 nm) for coal combustion fly ash (Davison et al., 1974), but in the µm range (0.1 – 0.5 µm) for biomass combustion fly ash (Nutalapati et al., 2007), due to a high percentage of ash vaporization in biomass combustion. Waste incineration fly ash may be similar to biomass combustion (high degree of ash vaporization)

*Dependence of concentration on particle size – the physical condensation theory:*
The mass fraction of a condensed species, $Wi(d_p)$ is given by the mass condensed (in time, t), on the particle of size $d_p$ divided by the particle mass.

Different condensation mechanisms will yield different dependencies of $F(d_p)$ on $d_p$, and it can be shown that for Kn<<1 (coarse fraction particles), $Wi(d_p) \sim 1/d_p^2$, while for Kn>>1 (fine fraction particles), $Wi(d_p) \sim 1/d_p$ (neglecting the Kelvin effect) (Neville & Sarofim, 1985, Davison et al., 1974).

Several studies of coal fly ash have, however, shown that experimental data are not always in consistence with this physical condensation theory (Neville and Sarofim, 1985; Davison et al., 1974). Often the trace elements (As, Ni, Cd etc.) better obey a $1/d_p$ dependence, even for larger particles, suggesting that surface condensation alone can not account for the trace element distribution (chemical reaction mechanisms are also involved).

**Fitting the FASAN data / validation of the model**
The FASAN fly ash was divided (experimentally) into 10 + 3 discrete size fractions: 10 aerosol fractions from LPI measurements and 3 fly ash sub samples (filter, filter house, undivided). Assuming that that the 10 aerosol fractions can be treated as one fraction with an average element concentration and an average geometric mean diameter (GMD) of 0.393 µm, these discrete fractions were used for data fitting. The condensation flux was calculated using equation (c) (condensation in the continuum regime, with correction for non-continuum behavior of small particles).

The Pb concentration in the FASAN ash as a function of particle diameter is illustrated in Figure 11 (measured and calculated values). The calculated value is a "first rough estimate" of the condensation flux, assuming an initial Pb concentration of 0.005 ppm(v) in the gas phase (based on gas data from Bøjer et al., 2008). At the point of sampling (T ~175 $^oC$), all Pb is assumed to be

condensed (as $PbCl_2(s)$). The initial Pb concentration ($C_0$) in the coarse particles is set to 697 mg/kg (residual concentration), while $C_0$ is set to 0 in the aerosols.

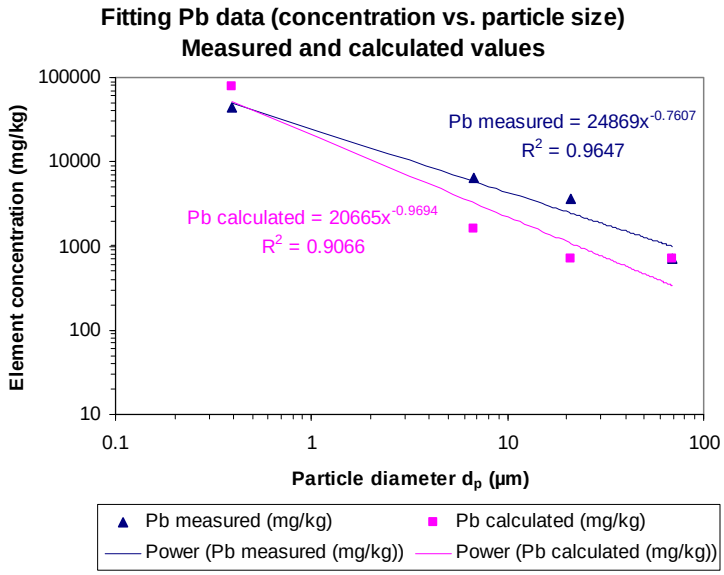



*Figure 11: Pb concentration in FASAN ash as a function of particle diameter. Measured and calculated values*

It is seen that the Pb concentration better obeys a $1/d_p$ dependence as compared to a $1/d_p^2$ dependence (the same trend is found for other trace elements as Hg, Cd, Zn and Cu, results not shown). The heterogeneous condensation model seems to correctly predict the trends in the experimental data, although it is also seen that the model may tend to over-estimate the Pb concentration in the fine particles.

**Model uncertainties**

Especially the quality of the input data - specifying the initial condition – is a very critical factor, which need further attention. In particular, there is a lack on reliable data for the degree of vaporization of elements from the grate during waste incineration. This could be a topic for future research projects.

The present model does not allow for chemical surface reactions. Including chemical surface reactions may improve the model, as our (and others) results indicate that surface condensation alone can not account for the trace element distribution.

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